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RECEIVER OPERATING CHARACTERISTICS AND PROCESSING GAIN OF A CLI--ETC(U)
FEB 70 L A BOELTER, E C JOHNSON

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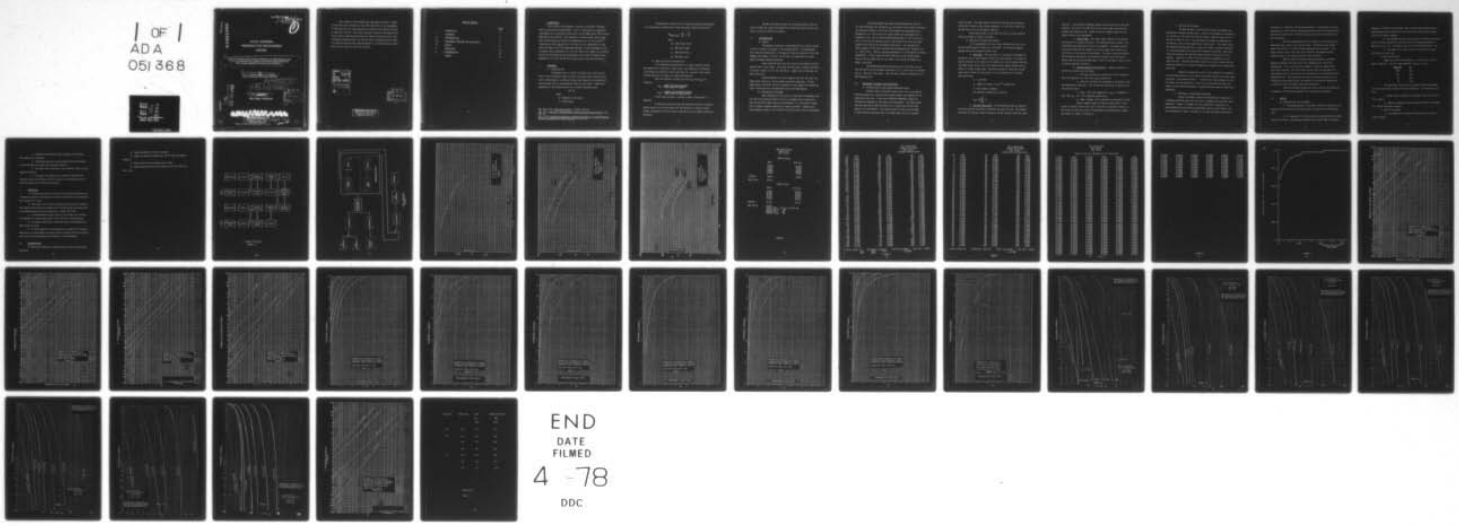

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NAVAL UNDERSEA
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CENTER

(6) RECEIVER OPERATING CHARACTERISTICS AND PROCESSING GAIN OF A CLIPPED DELTIC CORRELATOR USING PSEUDORANDOM AND LINEAR FREQUENCY MODULATED SIGNALS

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This technical note completes the experiment started by P. Hawkes of Code 3150 under SF-101-03-16, Task 11197 (NEL E11971). His measurement of the processing gain characteristics of a polarity coincidence correlator is reported in TM-1122. This report documents a polarity coincidence correlator's Receiver Operating Characteristics (ROC) and processing gain using a frequency modulated signal, and the ROC using a pseudorandom noise signal. This technical note has been prepared because it is believed that the information will be useful in this form to others.

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INTRODUCTION

This technical note documents a portion of Code 603's laboratory ROC and processing gain measurements. This is a continuation of laboratory experiments with a processing system similar to the LORAD system.[1] The original LORAD DELTIC was modified in the laboratory to provide sample rates of 200, 400, and 800 samples per second with bandwidths of 10, 30, 100 and 300.[2] Processing gain was measured with a PN signal for all combinations of bandwidth and sample rate.[3] This memorandum documents (1) ROC measurements using PN signals having bandwidths of 10, 30, 100, 300 Hz at a sample rate of 800 Hz, and (2) ROC and processing gain measurements using linear FM signals having bandwidths of 30, 100, and 300 Hz at sample rates of 200, 400, and 800 Hz.

I. BACKGROUND

A. Processing Gain

The apparent gain of a DELTIC correlator with a half wave detector is the difference between the input and output signal-to-noise ratios and is a measurement of a system efficiency when compared to the theoretical value obtained with the time-bandwidth product of the signal. Theoretical computation of the processing gain for a clipper correlator yields

$$PG = BT$$

where

B = Bandwidth of the signal

T = Pulse length

[1]NEL Report 1060, Lorad Status Report, 9 October 1961 (C).

[2]NUC TN 21, Laboratory Instrumentation Providing Multiple Sampling Rates, Sept 1967 (U).

[3]NEL TM 1122, Laboratory Experiments to Measure the Effects of Signal Bandwidth and System Sample Rate on Processing Gain, 21 June 1967.

The measured or actual gain of a processing system was determined in the laboratory by comparing the input and output signal-to-noise ratios.

$$PG_{(\text{measured})} = \frac{S_o}{N_o} \times \frac{N_1}{S_1}$$

where

S_o = peak output signal

S_1 = RMS input signal

N_o = RMS output noise

N_1 = RMS input noise

B. Receiver Operating Characteristic

This performance characteristic of a signal processor defines the probability of detecting a target (P_d) vs the probability of detection a non-target and producing a false alarm (P_{fa}) for a constant input signal-to-noise ratio and is a means for comparing processors.

With the threshold and input S/N fixed (P_d) and (P_{fa}) are defined as:

$$(P_d) = \frac{\text{number of targets detected}}{\text{total number of targets}}$$

$$(P_{fa}) = \frac{\text{number of non-targets detected}}{\text{total number of opportunities}}$$

If the input S/N ratio is varied, a family of ROC curves is generated.

It should be noted that these ROC represent the deltic correlator digital output such that one sample over the threshold is called a target. Further improvement of the ROC curves is possible by using computer clustering techniques.

The ROC curve data was taken at low signal-to-noise ratios because at higher S/N ratios the probability of false alarm fell to such a low value, it was very difficult to measure.

II. INSTRUMENTATION

A. General

The processor tested was a heterodyne DELTIC correlator (Figure 1) with 4.7 seconds of storage in the reference DELTIC. The pseudorandom noise signal was generated by a 15-stage shift register clocked at 4 KHz with feedback from stages 11 and 15. The FM signal was generated by a linear digital Frequency Modulated generator.

Input signal-to-noise ratio was varied by the addition of white gaussian noise to the signal. The signal and noise were filtered to the bands of interest, namely, 10, 30, 100, and 300 Hz. Sample rates of 200, 400, and 800 Hz were used.

A USQ-20 computer was used to measure the input S/N ratio, the output noise statistics, and the output correlation amplitudes. At each sample pulse a thirty-bit word was transferred to the computer for processing. Figure 2 shows the test instrumentation used in the measurements.

B. Heterodyning to Baseband

With a processor of this type it is desirable to heterodyne both the signal and reference signals to as low a frequency band as possible so that the available sample rates be used optimally; i.e., the ratio of sample rate to highest frequency sampled be as large as possible. However, with the equipment available it was difficult to do this readily for all bandwidths.

The FM measurements were made using heterodyning as follows: All three bandwidths were centered at f_c, the center of the transmit frequency. The reference channels of the 30 and 100 Hz bands were heterodyned with a frequency of (f_c + 50) Hz while the signal channel was heterodyned with a frequency of (f_c - 50) Hz, thereby generating basebands of -100 to 0 Hz and -65 to -35 Hz for the reference and 0 to 100 and 35 to 65 Hz for the signal channel of the 100 and 30 Hz bandwidth respectively. The reference and signal channels of the 300 Hz bandwidth were heterodyned with frequencies of f_c - 150 Hz and f_c - 250 Hz, generating basebands of 0 to 300 and 100 to 400 Hz, respectively. In this manner the 300 Hz band does not get folded around zero Hz, but the sample rate for the latter is only twice the highest frequency in the band.

The PN ROC measurements were made with all four bands (10, 30, 100, and 300 Hz) using heterodyne frequencies of (f_c + 50) Hz for the reference and (f_c - 50) Hz for the signal. Thus, the 300 Hz band was folded about the zero frequency axis.

III. MEASUREMENT TECHNIQUES AND CALCULATIONS

A. Processing Gain Using Frequency Modulated Signal

The RMS values of the DELTIC output noise, with an up-sweep FM reference channel and a gaussian noise signal channel, was computed for the output noise data base. A data base of 800,000 independent samples was collected and averaged for the output noise measurement. The output signal data base consisted of 200 correlations of a 5-second up-slide FM signal against a 4.7 FM reference. The output S/N was the ratio of the average of the correlation amplitude peaks to the RMS output noise at a constant

input S/N ratio. The input signal (FM up-slide) and input noise (gaussian white) were filtered to the selected bandwidth, i.e. 30, 100 or 300 Hz and the RMS values of each individually computed.

The processing gain vs the input S/N ratio at various sampling rates are plotted in Figures 3 through 5.

B. ROC Data for Pseudorandom Signals

In all measurements the input signal threshold was set to zero and the reference DELTIC loaded with a PN signal. The following computer programs were used to obtain the ROC curves.

1. <u>Noise Base</u> - The noise base is a statistical measurement of the output noise of the processor at the comb filter detector. An analog to digital converter at the output of the detector was used to separate the data into 4095 voltage levels, each level representing a sampled voltage falling within its .00244 voltage range. Counting the number of times each voltage level occurs allowed the calculation of P_i (the probability of a voltage level occurring).

$P_i = n_i/N$ where

n_i = Number of samples in the i^{th} voltage level

N = Total number of samples

The cumulative probability is found by

$$P_{cum} = \frac{1}{N} \sum_{n=1}^{L} n_1$$

2. <u>S/N Ratio Measurement</u> - The pseudorandom signal and gaussian noise were measured separately to determine the input S/N rato. The computer calculated the average, standard deviation, and RMS voltage of both the signal

and noise. Five thousand independent samples of each were used in the determination. The ratio of the RMS values of the input signal and noise were computed and converted to dB. Figure 6 shows the computer output for the signal-to-noise ratio measurement.

3. Output Signal - The output signal consists of two hundred correlations at a constant S/N ratio. The maximum amplitude of each of the correlations were sampled and stored in the computer. The output selected as the correlation was the highest of the three samples which contain the correlation as indicated by the PNG decoder. The output subroutine measured the two hundred correlations, calculated the average, stored the data on digital tape and printed the amplitudes in order of occurrence (Figure 7) and in order of amplitude (Figure 8).

4. Receiver Operating Characteristic - Computer generation of the ROC curve points were as follows:

a. The noise base data was searched to find the threshold where the probability of false alarm (P_{fa}) equaled 0.05.

b. Using this threshold the percentage of correlation above the threshold was determined. This defined the probability of detection for the given S/N ratio.

c. Steps 1 and 2 were repeated for (P_{fa}) in increments of 0.05 until P_{fa} = 1.0. This completed one ROC curve.

d. Steps 1 through 3 were repeated for each input S/N ratio.

Typical computer output for ROC curve data points is contained in Figures 9 and 10 and a plot of the data is contained in Figure 11. ROC curves for 300, 100, 30 and 10 Hz bandwidths pseudorandom noise signals are plotted in Figures 12 through 15.

C. ROC Data for FM Signals

The data obtained in the FM processing gain measurements was manipulated to produce the ROC curves. Plots of the probability of detection as a function of the false alarm rate for various input S/N ratios are contained in Figures 16 to 21. The thresholds are voltages corresponding to the abscissa values of the probability of false alarms. These curves relate the conditional probability that a signal will exceed a specified threshold if a given percentage of the non-signals exceeds the threshold. When correlators are compared, the correlator whose curve falls to the left is the superior. Figure 22 is a plot of the 100 and 300 Hz bandwidth at -14 db input S/N ratio. The 300 Hz bandwidth signal is to the left indicating that the 300 Hz bandwidth has a greater probability of detection for a given false alarm rate.

Figures 23 through 29 are plots of the probability of detection vs the standard deviation of the output noise above the mean for various input S/N ratios. The standard deviations are plotted for values between 0 and 28. The curves show the probability a signal with a known input S/N ratio will exceed a given threshold expressed in standard deviation above the mean noise background.

D. Differences in Measurement Techniques

Figures 16 through 21 contain the probability of detection of a frequency modulated pulse when the signal is compared with the total noise background. Figures 12 through 15 are the probability of detection of a pseudorandom noise pulse when the approximate location of the signal in the noise background is known. The former is a normal operational search while

the latter is a laboratory calibration measurement. Unfortunately the latter approach was not used with the frequency modulated pulse, but the FM generator could not be clocked with sufficient accuracy to pin point the locations of the correlations.

With the pseudorandom pulse the location of the correlation was determined from a count of the internal clock. Correlation occurs 18,800 pulses after the all "1" state of the pseudorandom noise generator. Five pulses on both sides of this count were sampled by the computer and the largest output in this region accepted as the correlation.

With the external frequency modulated generator a different method was employed since the clocks were independent and could not be synchronized. First a noise base was computed. Signal was added and the correlation recorded. The input signal-to-noise ratio was maintained at a level greater than -10 db to permit the correlations to be separated from the background noise. The output data was visually searched to locate the correlations and the processing gain and probability of detection computed with a calculator using the computer amplitude measurements.

Since two different methods were used to measure the probability of detection, the FM and pseudorandom noise data cannot be compared.

IV. RESULTS

A. Processing Gain for FM Signals

1. The processing gain of the DELTIC correlator increased as the input S/N ratio decreased and the gain tends to the limit of the theoretical gain.

2. An improvement in processing gain was observed when the sample rate was increased. Increasing the sampling rate to eight times the highest

frequency of the 100 Hz band limited signal increased the processing gain to approximately the gain observed with the 300 Hz band limited signal sampled at twice the highest frequency.

3. The maximum input S/N ratio for which the output correlations could be visually detected for the 300 Hz and 100 Hz bandwidths sampled at 800 Hz was -10 $\pm$ 1 db. The maximum input for the 30 Hz bandwidth was -6 db.

4. The output was a linear function of the input for input S/N ratios less than 0 db.

B. ROC for PN Signals

Comparison of the four bandwidths at a S/N ratio of -14 db is done in Figure 30. The Pd for the bandwidths with P_{fa} = 0.1% is:

Bandwidth	Pd
300	86%
100	70%
30	22%
10	12%

The improvement between 100 Hz bandwidth and 300 Hz bandwidth is not as significant as between the other bandwidths. Two reasons for this are:

1. Sample rate to bandwidth ratio changes from 8 at 100 Hz to 2.7 at 300 Hz.

2. There was frequency foldover because the DELTIC is designed for a 100 Hz difference frequency.

C. ROC for FM Signals

1. The probability of detection increased as the input S/N ratio increased.

2. Increasing the bandwidth and/or sampling rate increases the probability of detection.

3. The average output noise and standard deviation increased as the bandwidth and sampling rate decreased (Table 1).

4. The output noise amplitudes of the correlator tends to seven standard deviations.

5. In general, the probability of detection increased with increased sample rate; however, when the signal was over sampled at low S/N ratios the probability of detection decreased.

V. CONCLUSIONS

A. The processing gain characteristics of the DELTIC processor with a frequency modulated slide appeared to closely follow theoretical performance for a system of this type.

B. When signals with the same time-bandwidth products are compared, the frequency modulated slide produced similar processing gain characteristics as the pseudorandom noise pulse reported by P. Hawkes in TP-1122.

C. As time-bandwidth product increases, the PN ROC curve improved. The improvement is approximately equal to the increase in processing gain.

D. The highest probability of detection occurs when bandwidth and pulse length are large.

E. A direct comparison of the probability of detection of frequency modulated and a pseudorandom noise pulse cannot be obtained from this technical note since two different methods were employed in the measurements.

VI. RECOMMENDATIONS

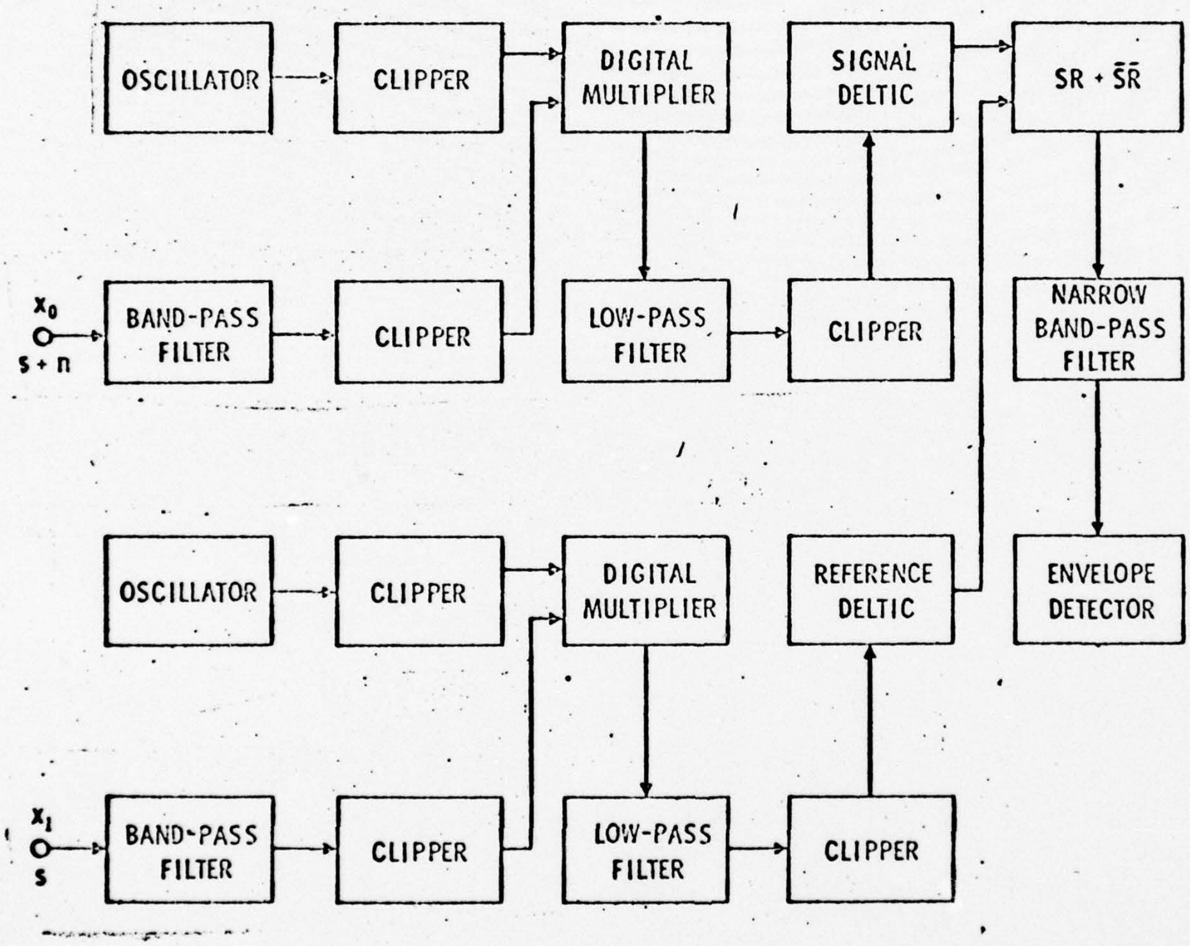
To improve the probability of detection with a polarity coincidence correlator:

A. Process bandwidths of 100 Hz or greater.

B. Sample the bandwidth between four and ten times the highest frequency.

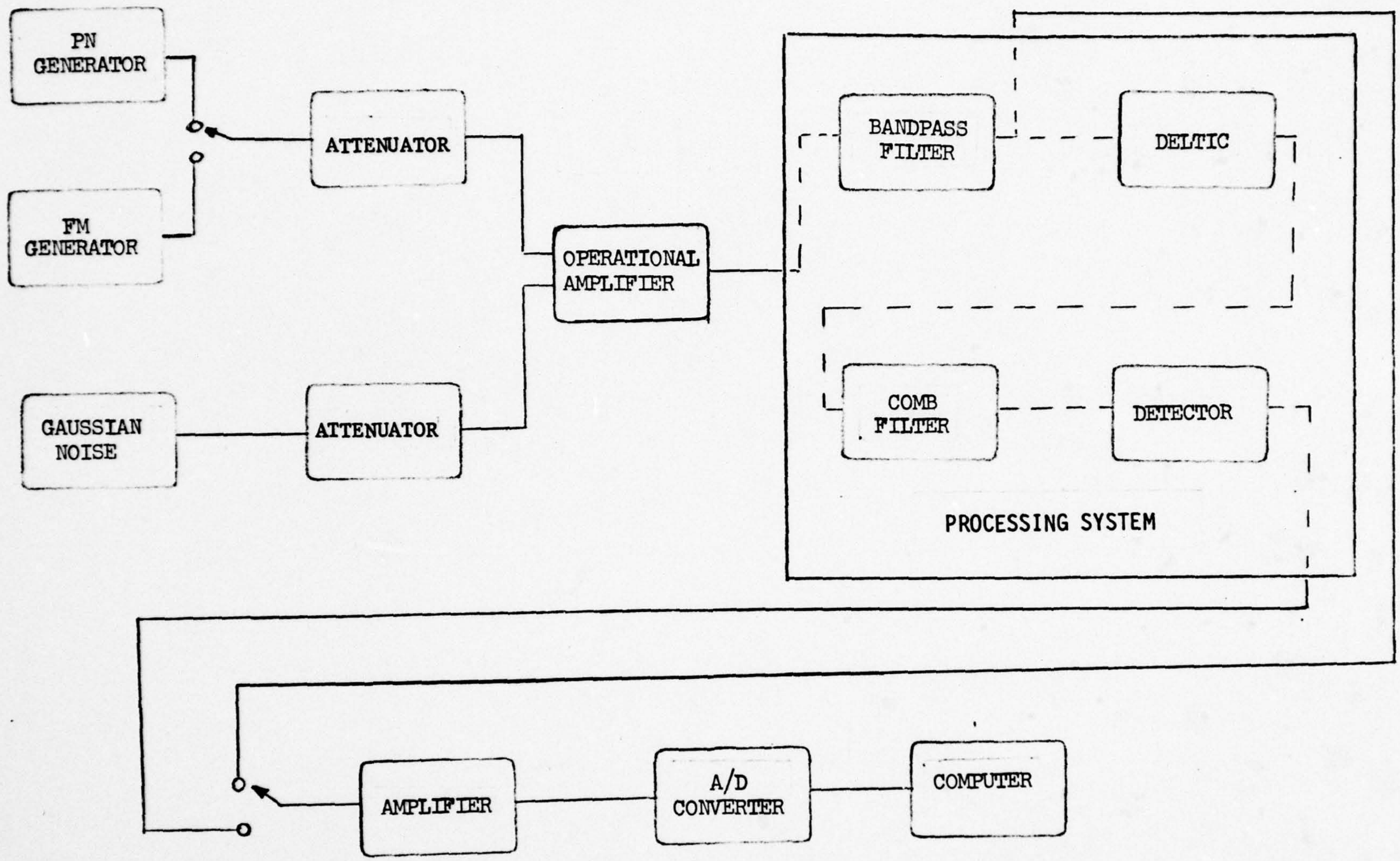
C. Operate with S/N ratios greater than -10 db.

D. Develop method for locating correlation with S/N ratios less than -10 db.



DELTIC CORRELATOR

FIGURE 1



TEST EQUIPMENT
FIGURE 2

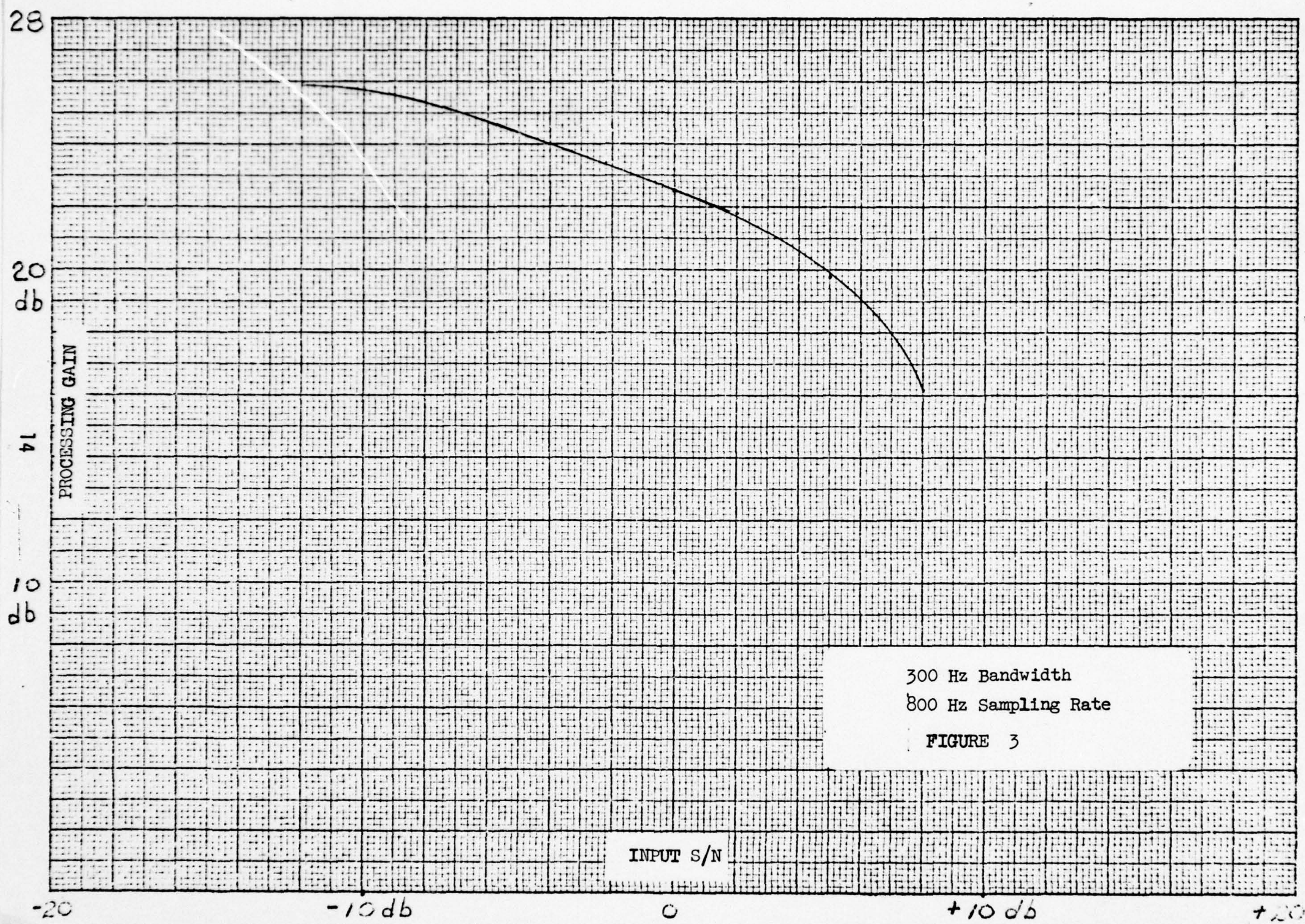
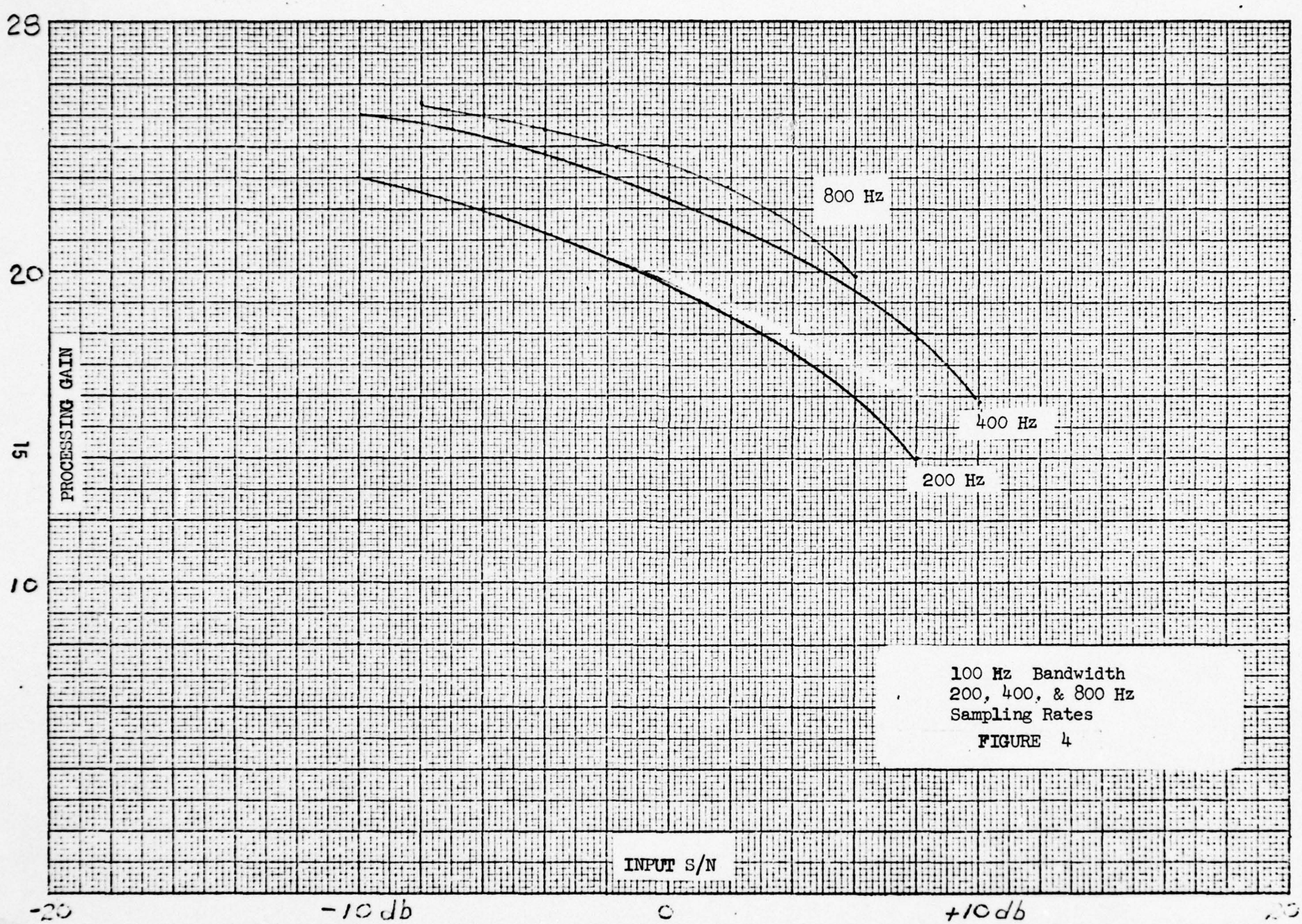
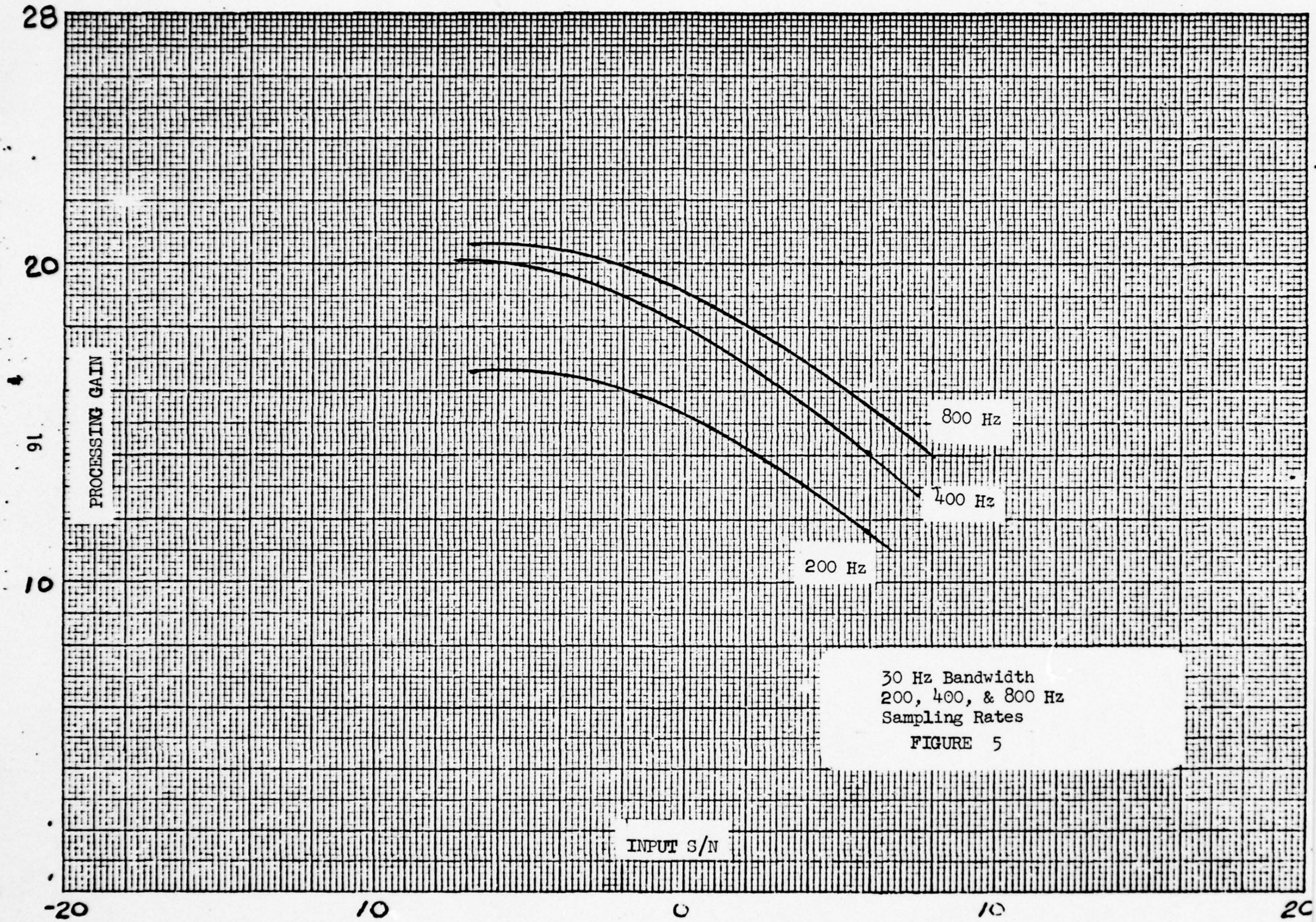

28
20 db
14
10 db
PROCESSING GAIN
INPUT S/N
-20
-10 db
0
+10 db
+20
300 Hz Bandwidth
800 Hz Sampling Rate

FIGURE 3



100 Hz Bandwidth
200, 400, & 800 Hz
Sampling Rates
FIGURE 4



30 Hz Bandwidth
200, 400, & 800 Hz
Sampling Rates
FIGURE 5

ROC EXPERIMENT
INPUT S/N
MAY 16 68

INPUT SIGNAL

	MEAN	STD DEV
	0.064	0.036
	0.065	0.036
	0.064	0.036
	0.064	0.036
	0.063	0.036
AVERAGE	0.064	0.036
RMS VOLTS	0.074	

INPUT NOISE

	MEAN	STD DEV
	0.369	0.276
	0.370	0.277
	0.375	0.280
	0.366	0.275
	0.366	0.275
AVERAGE	0.369	0.277
RMS VOLTS	0.462	

INPUT S/N = 0.161 =-15.85 DB
SAMPLE RATE= 800
BANDWIDTH= 300
SIGNAL TYPE= PN

FIGURE 6

ROC EXPERIMENT
SIGNAL DATA BASE
MAY 16 68
ORDERED CORRELATIONS

NO	AMP	NO	AMP	NO	AMP
118	0.156	87	0.720	79	0.937
162	0.297	25	0.735	97	0.937
109	0.307	55	0.735	107	0.937
193	0.349	173	0.737	179	0.954
12	0.380	111	0.739	132	0.962
74	0.402	67	0.747	115	0.964
28	0.424	91	0.754	188	0.964
159	0.429	44	0.757	189	0.976
138	0.432	104	0.761	160	0.979
81	0.437	192	0.791	58	0.981
139	0.439	99	0.793	101	0.981
141	0.439	100	0.793	64	0.986
19	0.454	51	0.805	68	0.988
122	0.459	171	0.813	30	0.993
54	0.493	114	0.820	77	0.993
186	0.493	62	0.832	170	0.993
36	0.525	24	0.840	56	0.996
102	0.537	8	0.842	38	1.006
154	0.551	46	0.844	120	1.013
57	0.556	14	0.847	60	1.015
1	0.559	75	0.847	158	1.015
152	0.561	156	0.847	18	1.020
35	0.564	112	0.852	172	1.028
135	0.571	70	0.857	15	1.030
124	0.578	161	0.859	167	1.030
6	0.583	33	0.864	22	1.035
200	0.588	197	0.866	144	1.035
41	0.593	31	0.871	93	1.042
21	0.598	84	0.871	121	1.045
43	0.608	146	0.874	42	1.054
16	0.610	148	0.874	61	1.059
66	0.612	151	0.874	26	1.062
96	0.625	95	0.886	78	1.062
147	0.625	98	0.886	185	1.064
163	0.627	164	0.893	149	1.079
17	0.634	52	0.896	136	1.093
166	0.642	106	0.896	116	1.096
184	0.644	13	0.898	40	1.098
27	0.656	89	0.898	90	1.098
76	0.664	145	0.908	196	1.103
88	0.666	23	0.910	177	1.113
183	0.671	73	0.913	194	1.115
65	0.678	10	0.920	153	1.120
103	0.678	53	0.920	32	1.125
180	0.681	126	0.920	3	1.140
29	0.698	5	0.923	175	1.142
80	0.703	168	0.925	105	1.150
178	0.710	4	0.930	113	1.150
128	0.713	125	0.932	169	1.172
134	0.715	72	0.935	187	1.172

SIGNAL TYPE= PN   BANDWIDTH= 300 CPS   INPUT S/N= ~~18.2~~ -15.85   AVG AMP= 0.985

LIB   PLOT   34741
TRA   7000

FIGURE 7

ROC EXPERIMENT
SIGNAL DATA BASE
MAY 16 68
SEQUENTIAL CORRELATIONS

NO	AMP	NO	AMP	NO	AMP
1	0.559	51	0.805	101	0.981
2	1.274	52	0.896	102	0.537
3	1.140	53	0.920	103	0.678
4	0.930	54	0.493	104	0.761
5	0.923	55	0.735	105	1.150
6	0.583	56	0.996	106	0.896
7	1.313	57	0.556	107	0.937
8	0.842	58	0.981	108	1.536
9	1.369	59	1.775	109	0.307
10	0.920	60	1.015	110	1.377
11	6.564	61	1.059	111	0.739
12	0.380	62	0.832	112	0.852
13	0.898	63	1.411	113	1.150
14	0.847	64	0.986	114	0.820
15	1.030	65	0.678	115	0.964
16	0.610	66	0.612	116	1.096
17	0.634	67	0.747	117	1.418
18	1.020	68	0.988	118	0.156
19	0.454	69	1.260	119	1.531
20	1.479	70	0.857	120	1.013
21	0.598	71	1.387	121	1.045
22	1.035	72	0.935	122	0.459
23	0.910	73	0.913	123	1.865
24	0.840	74	0.402	124	0.578
25	0.735	75	0.847	125	0.932
26	1.062	76	0.664	126	0.920
27	0.656	77	0.993	127	1.460
28	0.424	78	1.062	128	0.713
29	0.698	79	0.937	129	1.216
30	0.993	80	0.703	130	1.523
31	0.871	81	0.437	131	1.604
32	1.125	82	1.245	132	0.962
33	0.864	83	1.279	133	1.184
34	1.445	84	0.871	134	0.715
35	0.564	85	1.306	135	0.571
36	0.525	86	1.550	136	1.093
37	1.235	87	0.720	137	1.365
38	1.006	88	0.666	138	0.432
39	1.223	89	0.898	139	0.439
40	1.098	90	1.098	140	1.242
41	0.593	91	0.754	141	0.439
42	1.054	92	1.702	142	1.269
43	0.608	93	1.042	143	1.264
44	0.757	94	1.255	144	1.035
45	1.252	95	0.886	145	0.908
46	0.844	96	0.625	146	0.874
47	1.213	97	0.937	147	0.625
48	1.672	98	0.886	148	0.874
49	1.394	99	0.793	149	1.079
50	1.255	100	0.793	150	1.487

SIGNAL TYPE= PN   BANDWIDTH= 300 CPS   INPUT S/N= ~~18.2~~ -15.85   AVG AMP= 0.985

FIGURE 8

ROC EXPERIMENT
ROC CURVE
MAY 16 68

FALSE ALARM VS. PROBABILITY OF DETECTION

FARATE	PROB	FARATE	PROB	FARATE	PROB
0.0000	0.0000	0.3350	0.9850	0,6700	0,9950
0.0050	0.4850	0.3400	0.9850	0,6750	0,9950
0.0100	0.6150	0.3450	0.9850	0,6800	0,9950
0.0150	0.6800	0.3500	0.9850	0,6850	0,9950
0.0200	0.7050	0.3550	0.9850	0,6900	0,9950
0.0250	0.7150	0.3600	0.9850	0,6950	0,9950
0.0300	0.7450	0.3650	0.9850	0,7000	0,9950
0.0350	0.7600	0.3700	0.9850	0,7050	0,9950
0.0400	0.7750	0.3750	0.9850	0,7100	0,9950
0.0450	0.7900	0.3800	0.9850	0,7150	1,0000
0.0500	0.8050	0.3850	0.9850	0,7200	1,0000
0.0550	0.8100	0.3900	0.9850	0,7250	1,0000
0.0600	0.8200	0.3950	0.9850	0,7300	1,0000
0.0650	0.8400	0.4000	0.9850	0,7350	1,0000
0.0700	0.8400	0.4050	0.9900	0,7400	1,0000
0.0750	0.8550	0.4100	0.9900	0,7450	1,0000
0.0800	0.8600	0.4150	0.9900	0,7500	1,0000
0.0850	0.8700	0.4200	0.9900	0,7550	1,0000
0.0900	0.8800	0.4250	0.9950	0,7600	1,0000
0.0950	0.8850	0.4300	0.9950	0,7650	1,0000
0.1000	0.8950	0.4350	0.9950	0,7700	1,0000
0.1050	0.9100	0.4400	0.9950	0,7750	1,0000
0.1100	0.9100	0.4450	0.9950	0,7800	1,0000
0.1150	0.9100	0.4500	0.9950	0,7850	1,0000
0.1200	0.9150	0.4550	0.9950	0,7900	1,0000
0.1250	0.9200	0.4600	0.9950	0,7950	1,0000
0.1300	0.9200	0.4650	0.9950	0,8000	1,0000
0.1350	0.9200	0.4700	0.9950	0,8050	1,0000
0.1400	0.9200	0.4750	0.9950	0,8100	1,0000
0.1450	0.9200	0.4800	0.9950	0,8150	1,0000
0.1500	0.9300	0.4850	0.9950	0,8200	1,0000
0.1550	0.9300	0.4900	0.9950	0,8250	1,0000
0.1600	0.9300	0.4950	0.9950	0,8300	1,0000
0.1650	0.9300	0.5000	0.9950	0,8350	1,0000
0.1700	0.9300	0.5050	0.9950	0,8400	1,0000
0.1750	0.9300	0.5100	0.9950	0,8450	1,0000
0.1800	0.9300	0.5150	0.9950	0,8500	1,0000
0.1850	0.9350	0.5200	0.9950	0,8550	1,0000
0.1900	0.9400	0.5250	0.9950	0,8600	1,0000
0.1950	0.9400	0.5300	0.9950	0,8650	1,0000
0.2000	0.9400	0.5350	0.9950	0,8700	1,0000
0.2050	0.9500	0.5400	0.9950	0,8750	1,0000
0.2100	0.9550	0.5450	0.9950	0,8800	1,0000
0.2150	0.9600	0.5500	0.9950	0,8850	1,0000
0.2200	0.9650	0.5550	0.9950	0,8900	1,0000
0.2250	0.9700	0.5600	0.9950	0,8950	1,0000
0.2300	0.9700	0.5650	0.9950	0,9000	1,0000
0.2350	0.9700	0.5700	0.9950	0,9050	1,0000
0.2400	0.9700	0.5750	0.9950	0,9100	1,0000
0.2450	0.9700	0.5800	0.9950	0,9150	1,0000
0.2500	0.9750	0.5850	0.9950	0,9200	1,0000
0.2550	0.9750	0.5900	0.9950	0,9250	1,0000
0.2600	0.9750	0.5950	0.9950	0,9300	1,0000
0.2650	0.9750	0.6000	0.9950	0,9350	1,0000

FIGURE 9

0.2700	0.9750	0.6050	0.9950	0.9400	1.0000
0.2750	0.9750	0.6100	0.9950	0.9450	1.0000
0.2800	0.9750	0.6150	0.9950	0.9500	1.0000
0.2850	0.9800	0.6200	0.9950	0.9550	1.0000
0.2900	0.9800	0.6250	0.9950	0.9600	1.0000
0.2950	0.9800	0.6300	0.9950	0.9650	1.0000
0.3000	0.9800	0.6350	0.9950	0.9700	1.0000
0.3050	0.9800	0.6400	0.9950	0.9750	1.0000
0.3100	0.9800	0.6450	0.9950	0.9800	1.0000
0.3150	0.9800	0.6500	0.9950	0.9850	1.0000
0.3200	0.9800	0.6550	0.9950	0.9900	1.0000
0.3250	0.9800	0.6600	0.9950	0.9950	1.0000
0.3300	0.9800	0.6650	0.9950	1.0000	1.0000

FIGURE 10

201

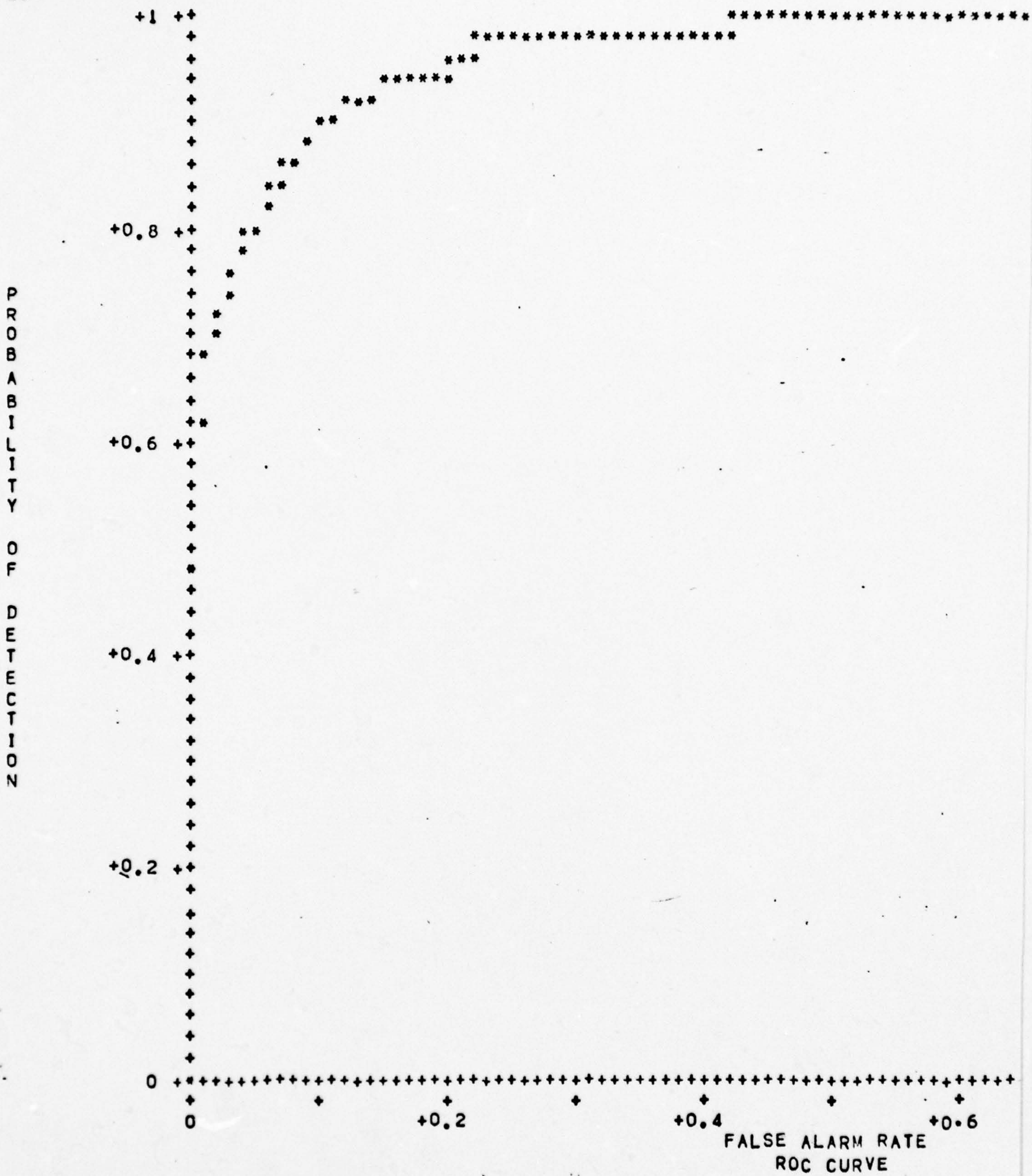
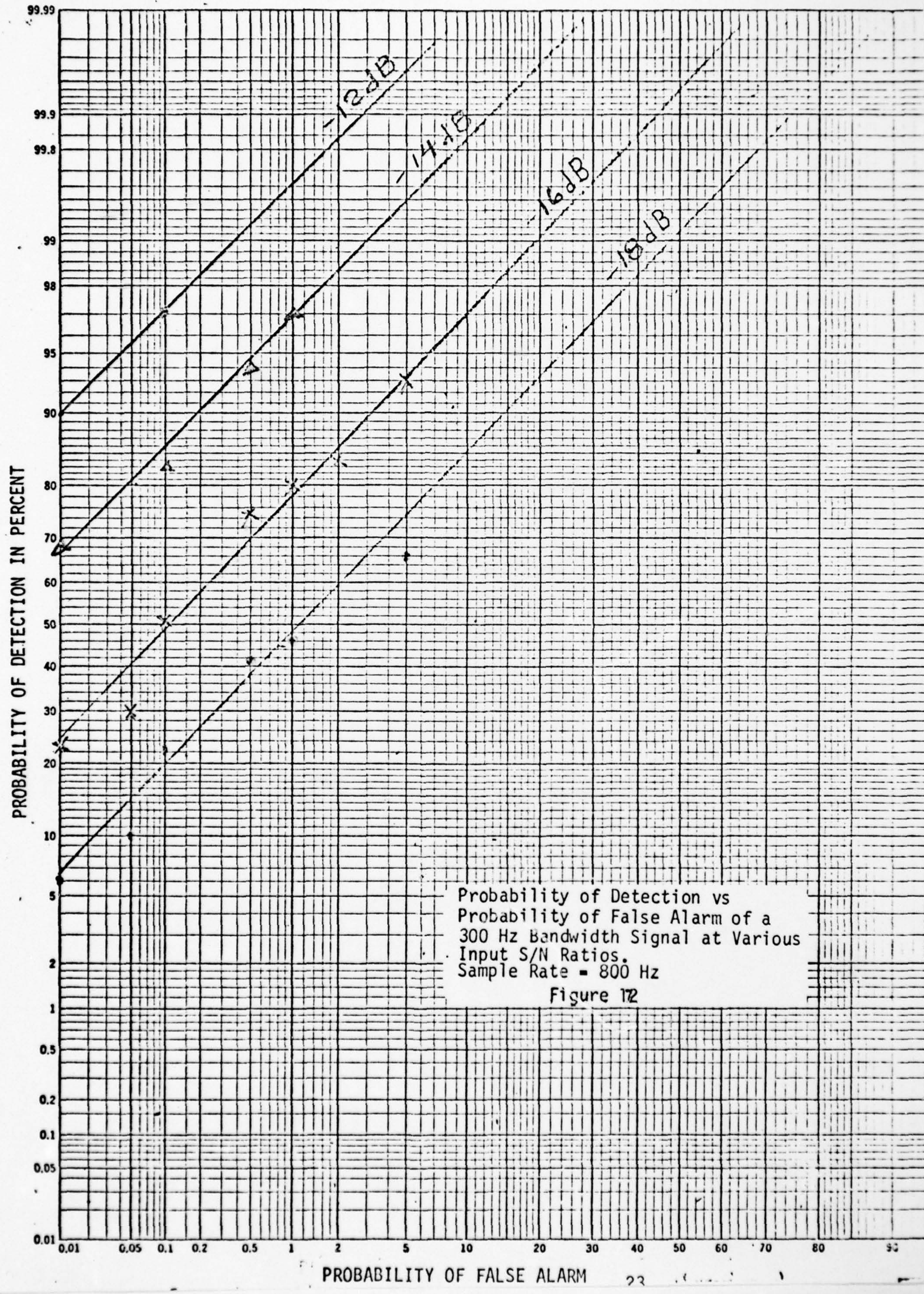
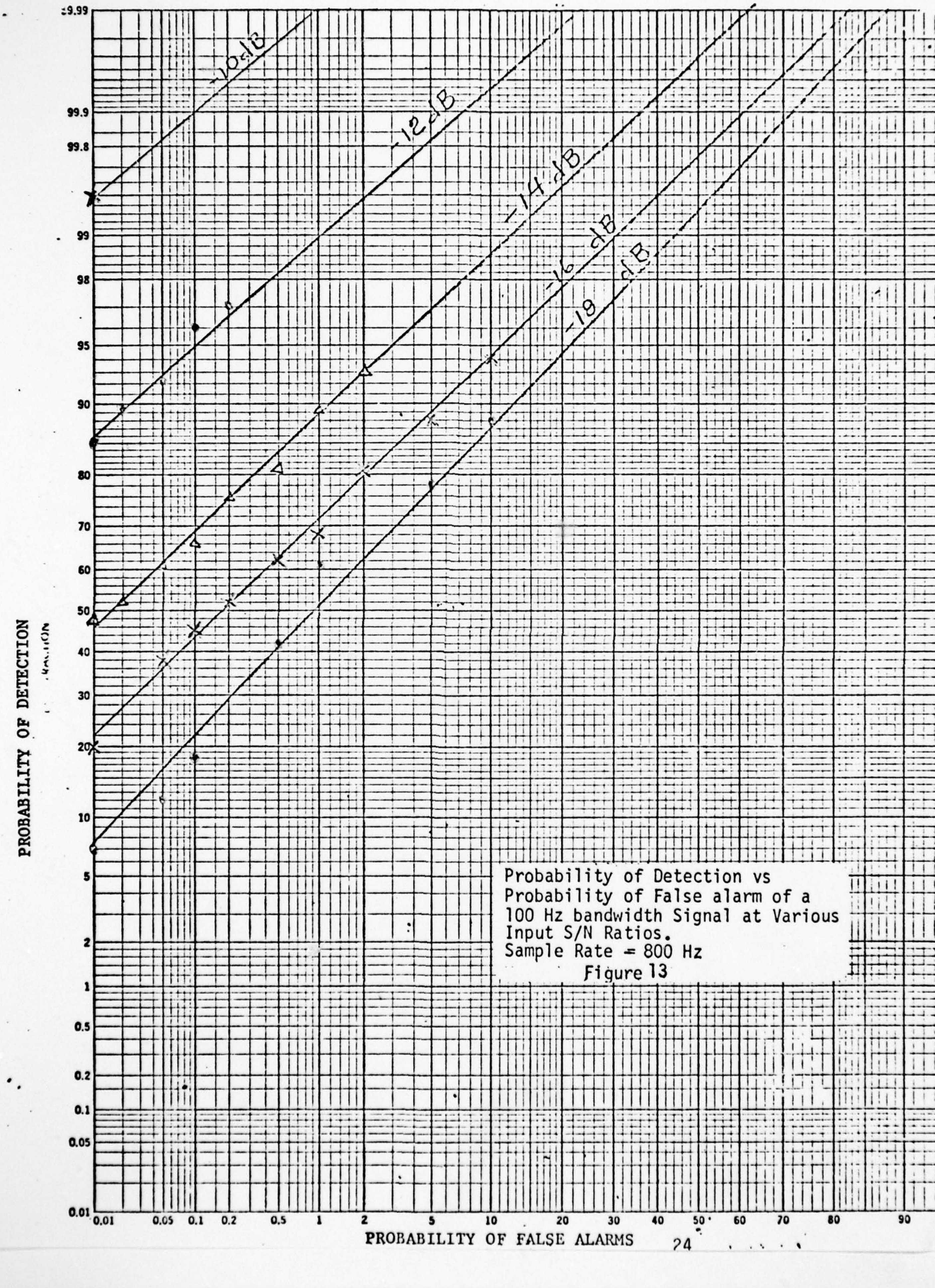


FIGURE 11

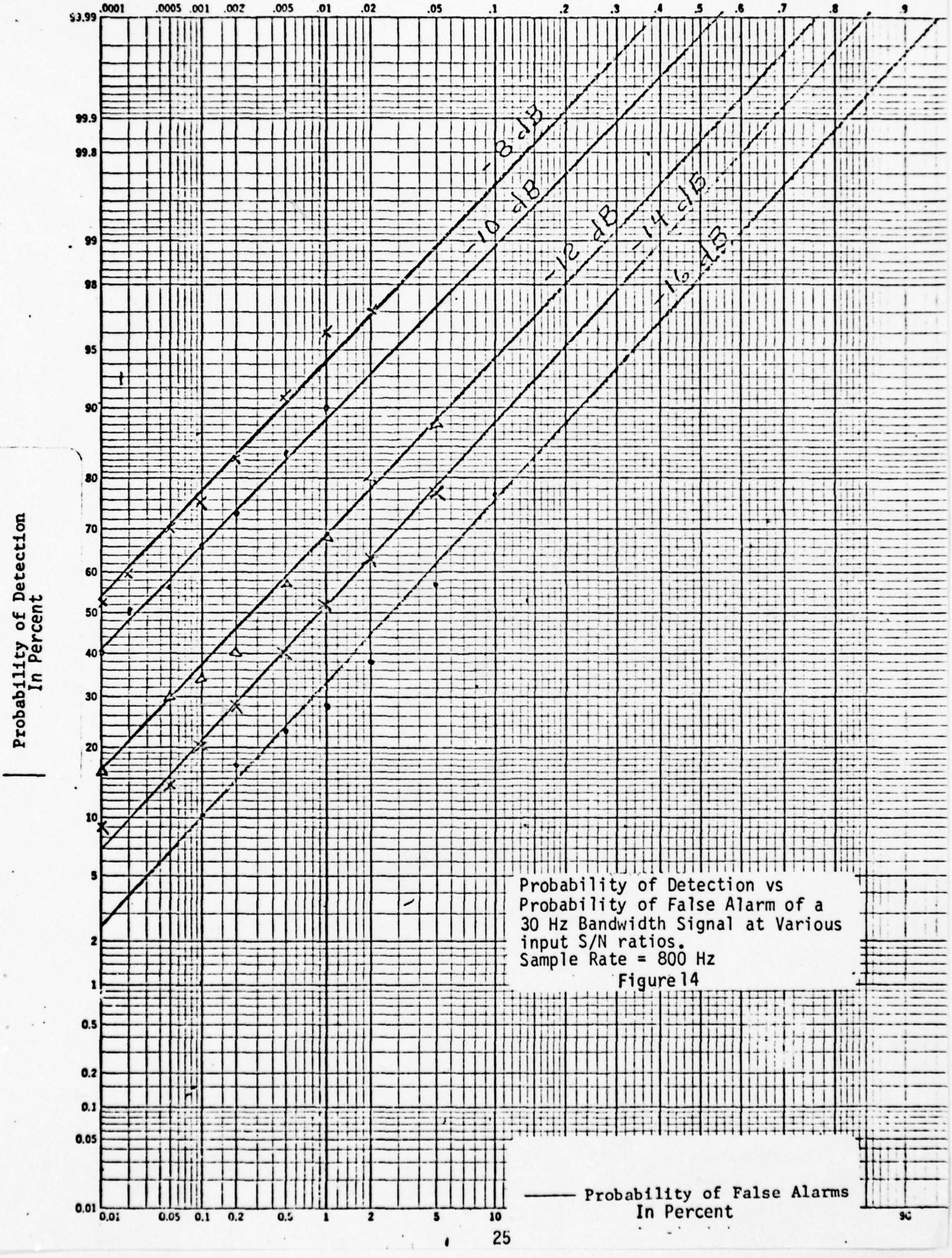


Probability of Detection vs
Probability of False Alarm of a
300 Hz Bandwidth Signal at Various
Input S/N Ratios.
Sample Rate = 800 Hz

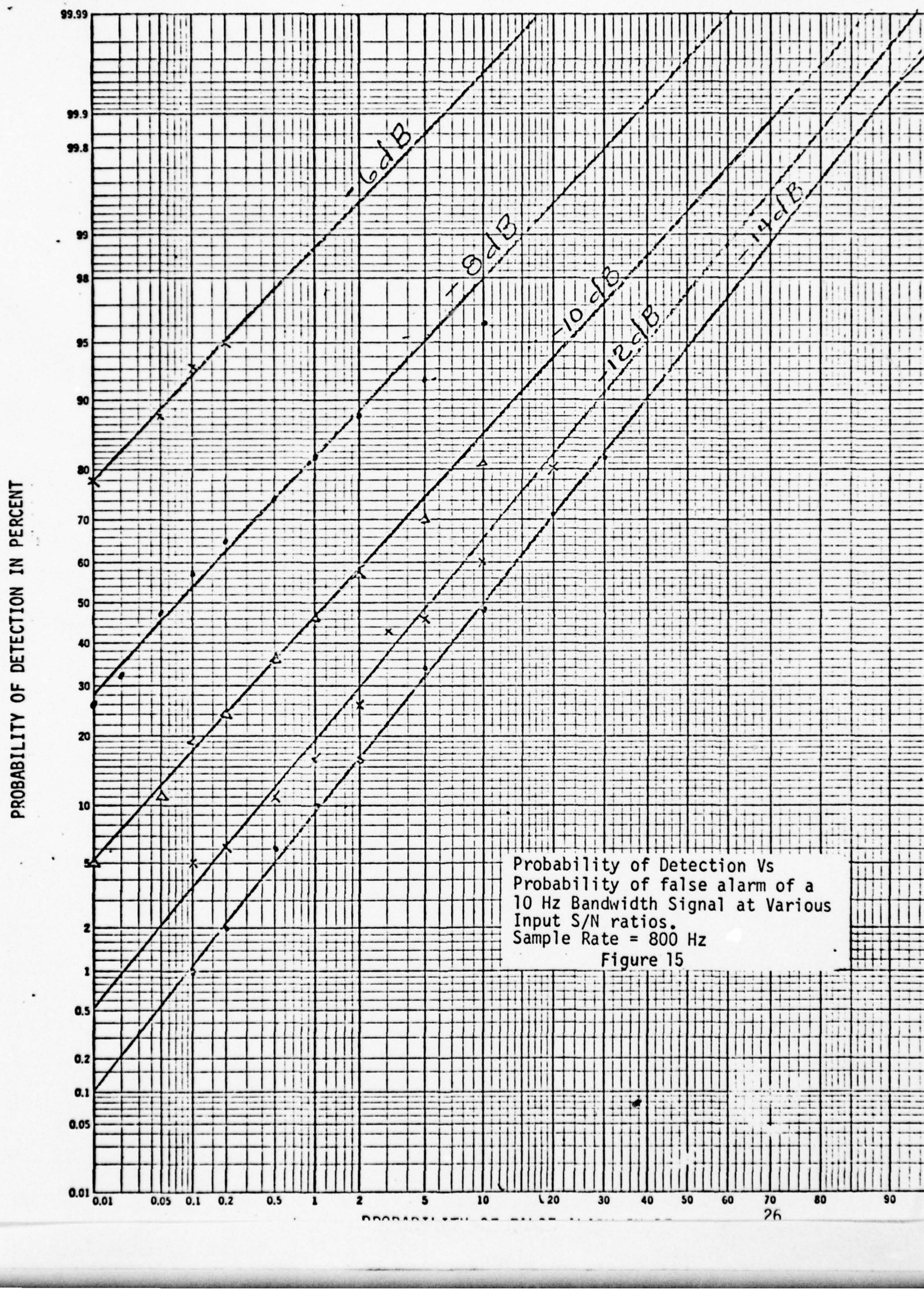
Figure 12



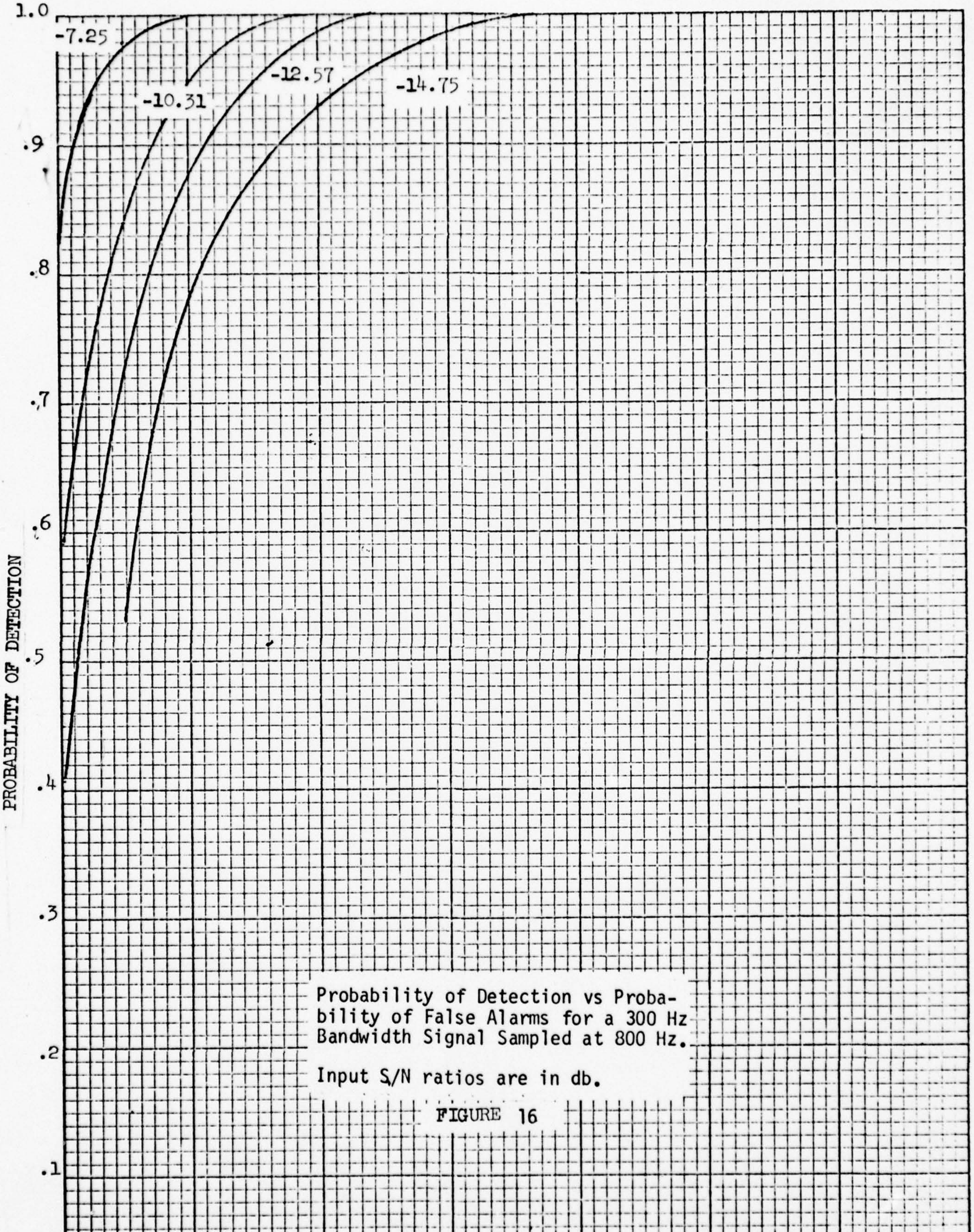
Probability of Detection vs
Probability of False alarm of a
100 Hz bandwidth Signal at Various
Input S/N Ratios.
Sample Rate = 800 Hz
Figure 13



Probability of Detection vs Probability of False Alarm of a 30 Hz Bandwidth Signal at Various input S/N ratios.
Sample Rate = 800 Hz
Figure 14



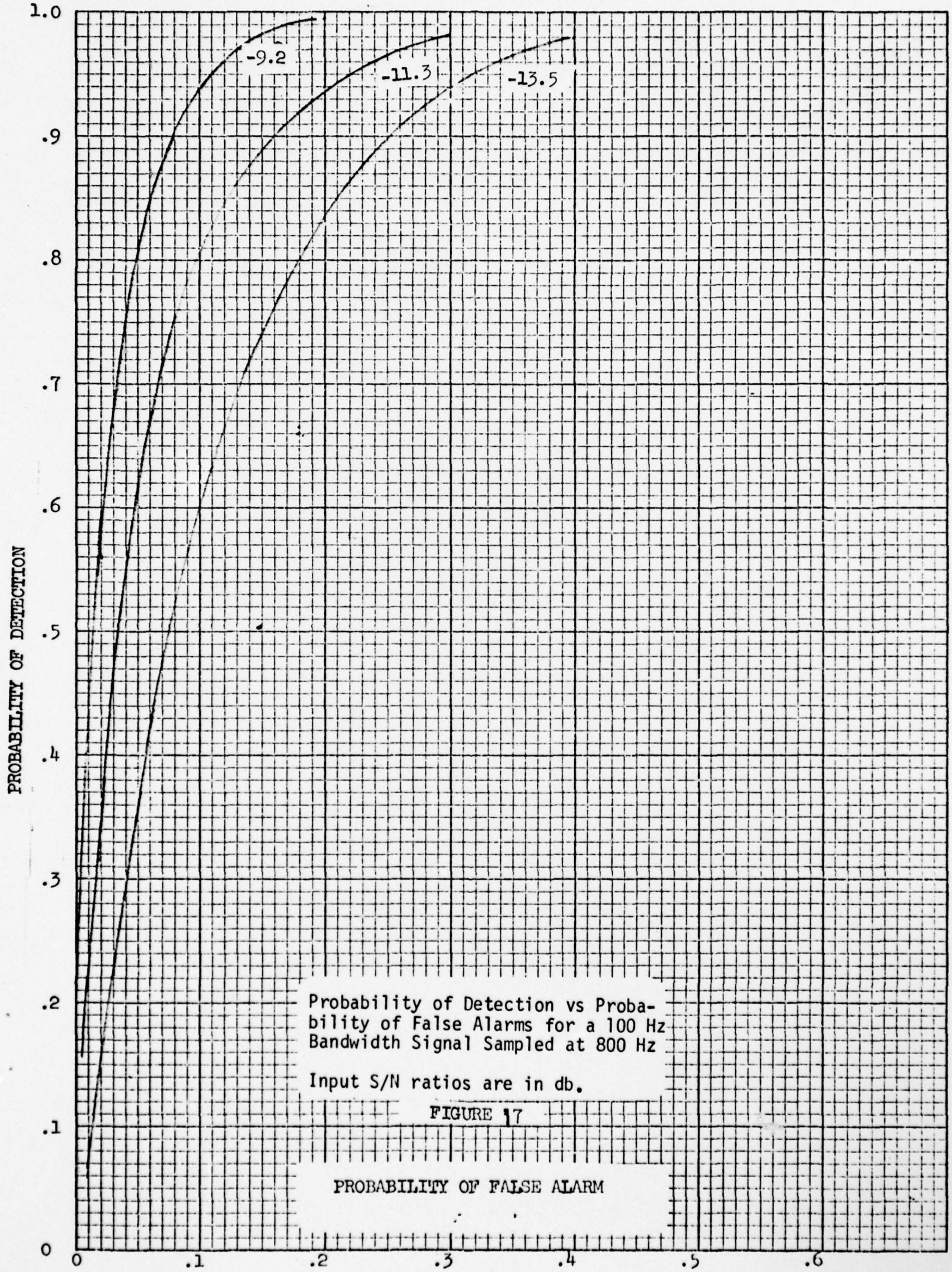
Probability of Detection Vs
Probability of false alarm of a
10 Hz Bandwidth Signal at Various
Input S/N ratios.
Sample Rate = 800 Hz
Figure 15



Probability of Detection vs Probability of False Alarms for a 300 Hz Bandwidth Signal Sampled at 800 Hz.

Input S/N ratios are in db.

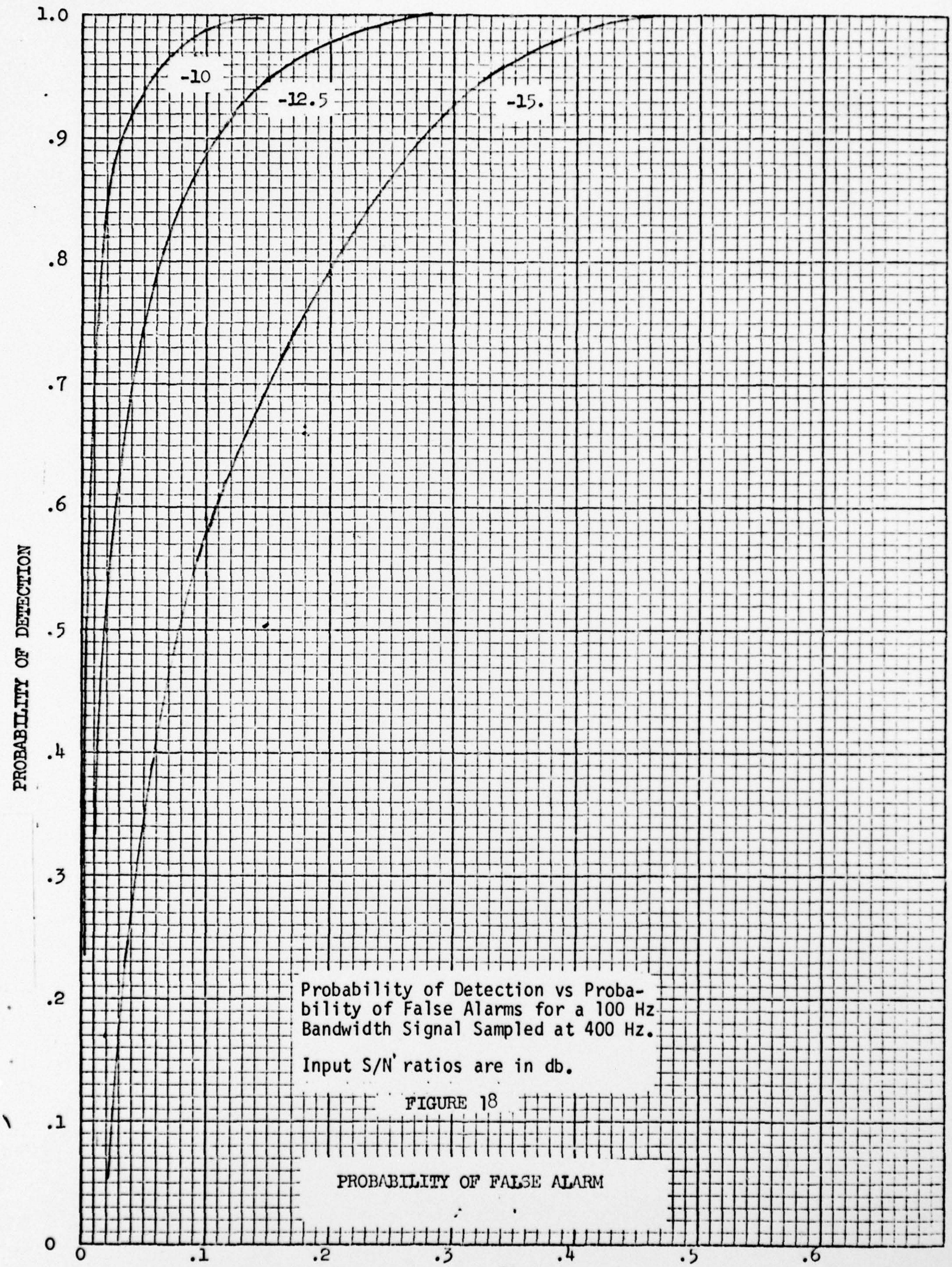
FIGURE 16



Probability of Detection vs Probability of False Alarms for a 100 Hz Bandwidth Signal Sampled at 800 Hz

Input S/N ratios are in db.

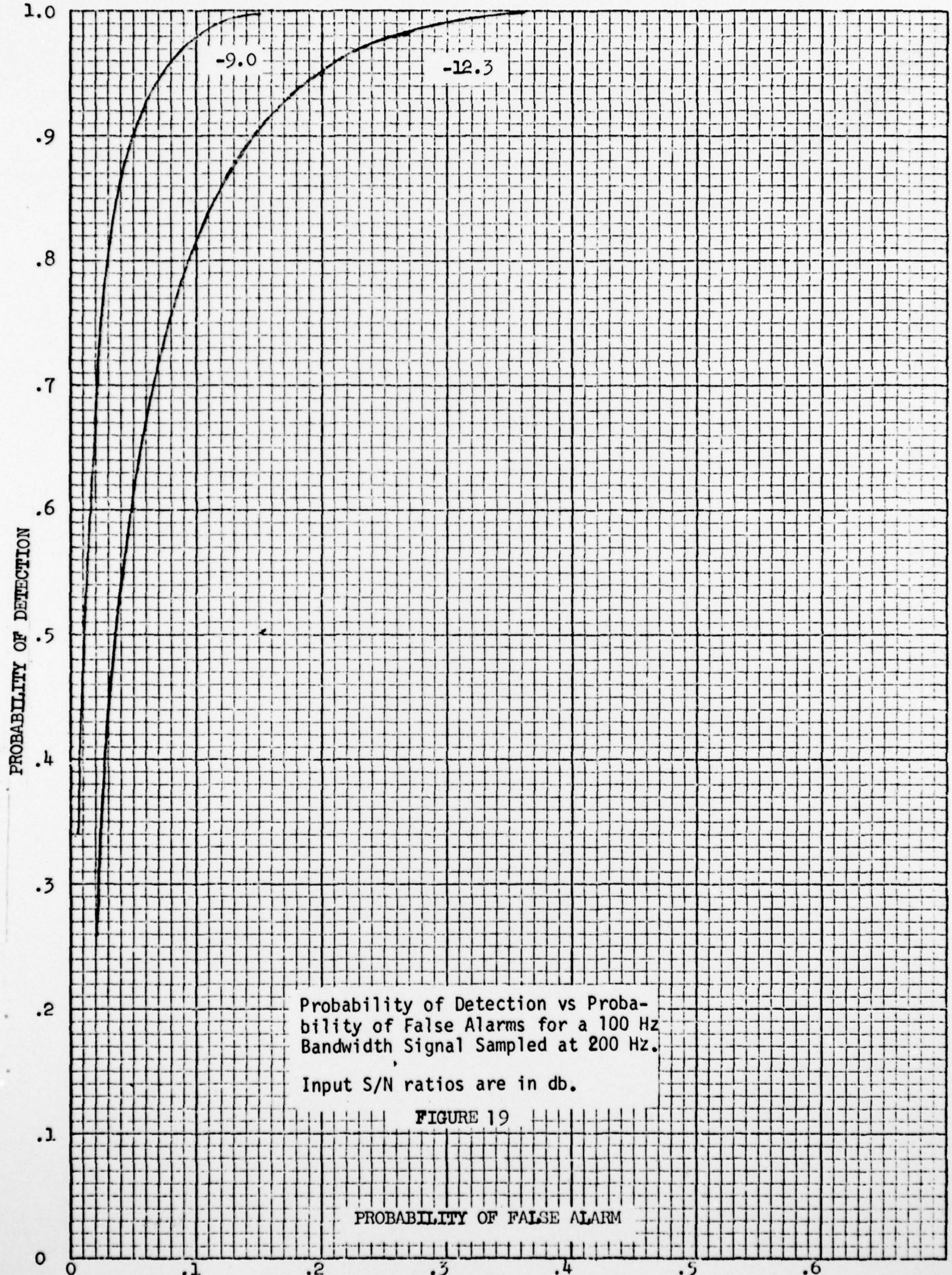
FIGURE 17



Probability of Detection vs Probability of False Alarms for a 100 Hz Bandwidth Signal Sampled at 400 Hz.

Input S/N ratios are in db.

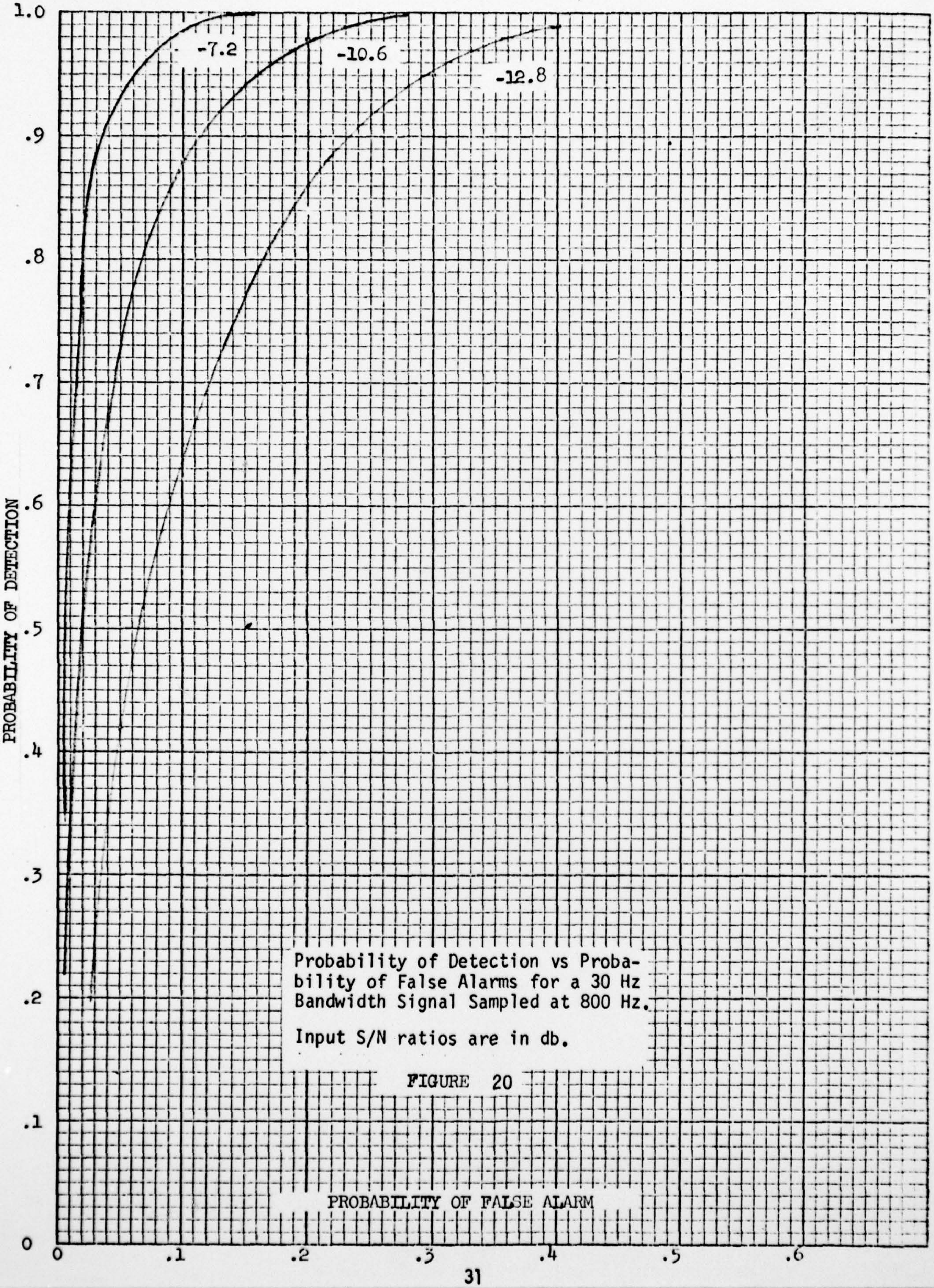
FIGURE 18



Probability of Detection vs Probability of False Alarms for a 100 Hz Bandwidth Signal Sampled at 200 Hz.

Input S/N ratios are in db.

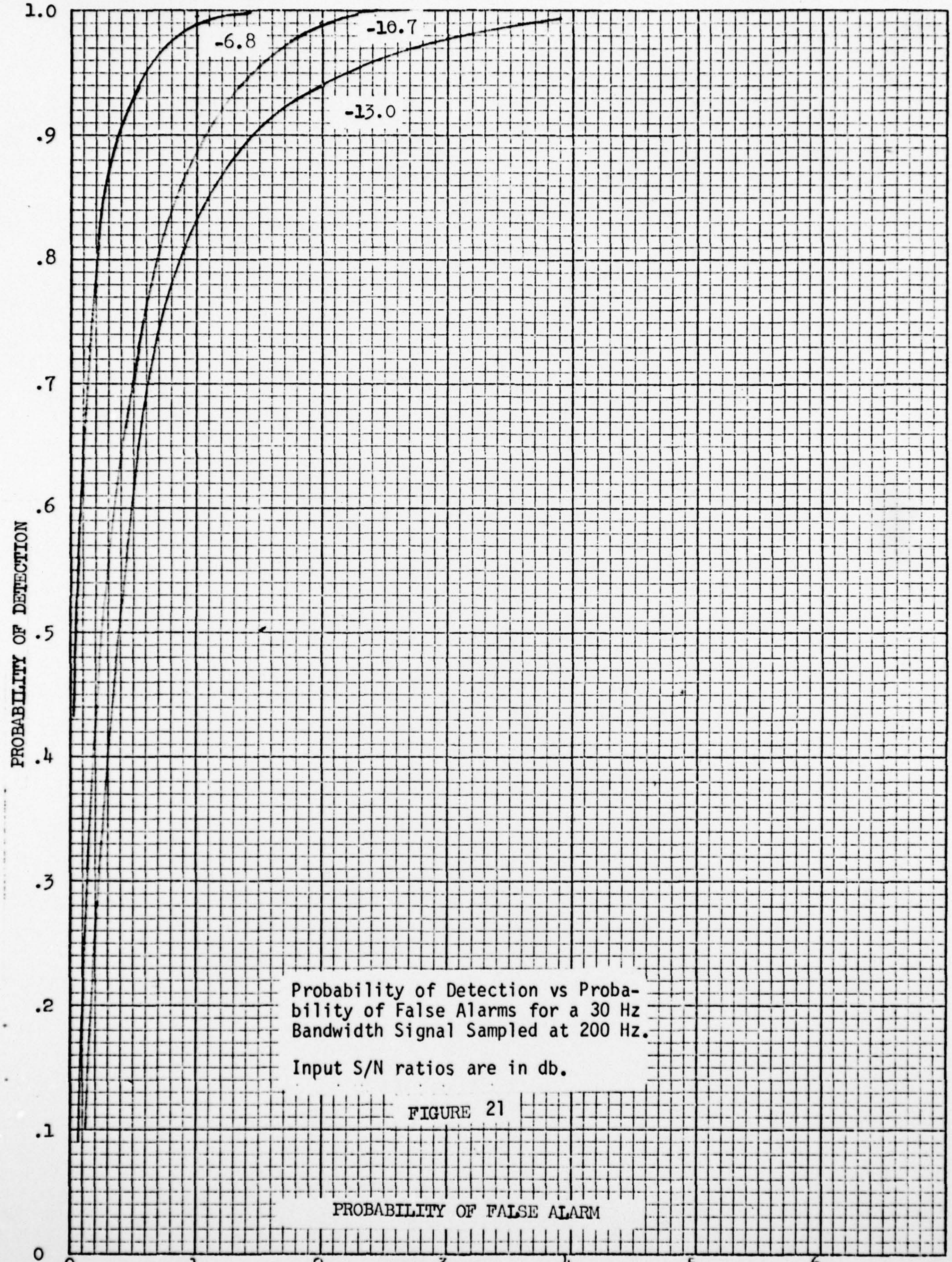
FIGURE 19



Probability of Detection vs Probability of False Alarms for a 30 Hz Bandwidth Signal Sampled at 800 Hz.

Input S/N ratios are in db.

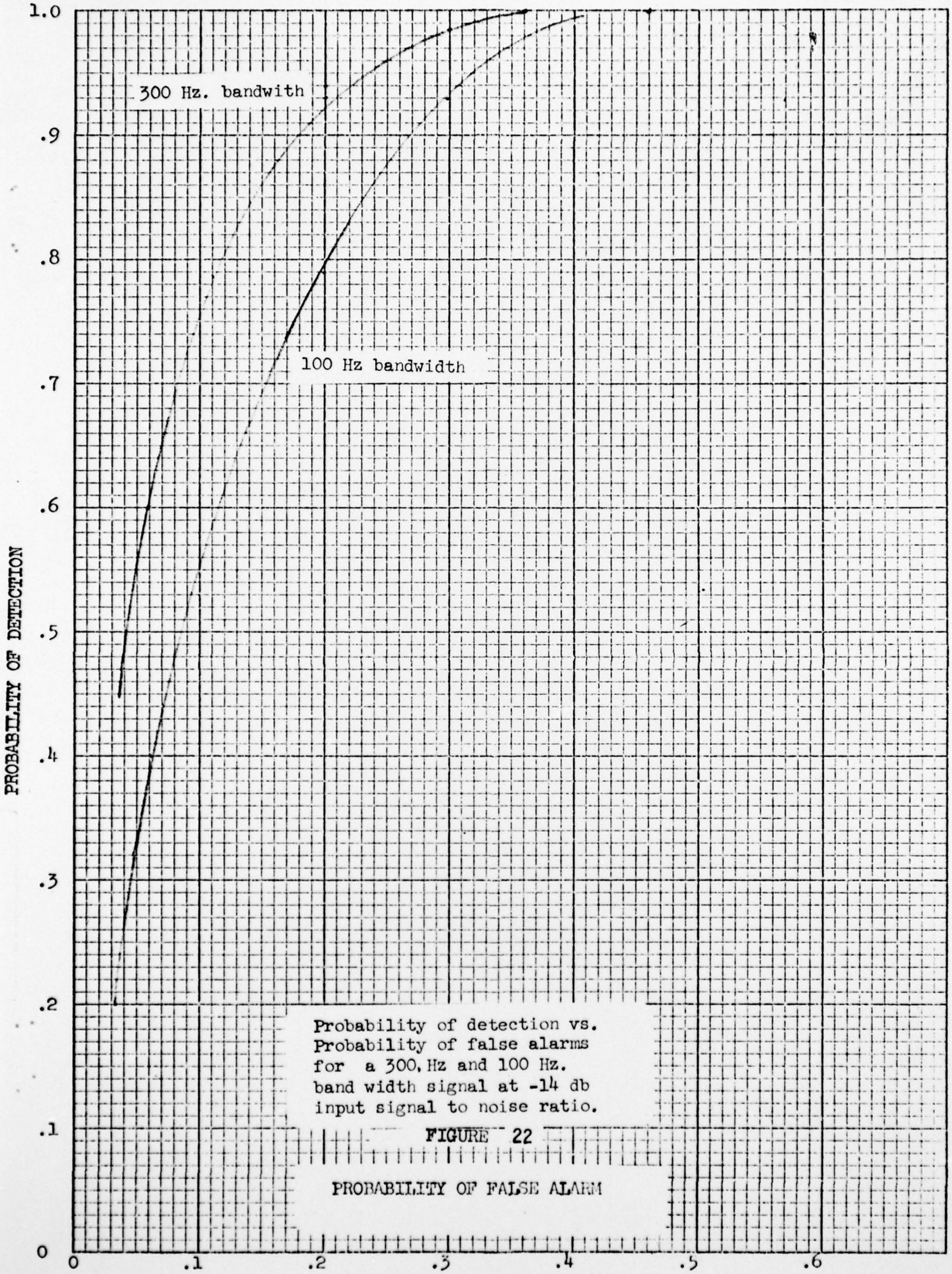
FIGURE 20



Probability of Detection vs Probability of False Alarms for a 30 Hz Bandwidth Signal Sampled at 200 Hz.

Input S/N ratios are in db.

FIGURE 21



Probability of detection vs.
Probability of false alarms
for a 300 Hz and 100 Hz.
band width signal at -14 db
input signal to noise ratio.

FIGURE 22

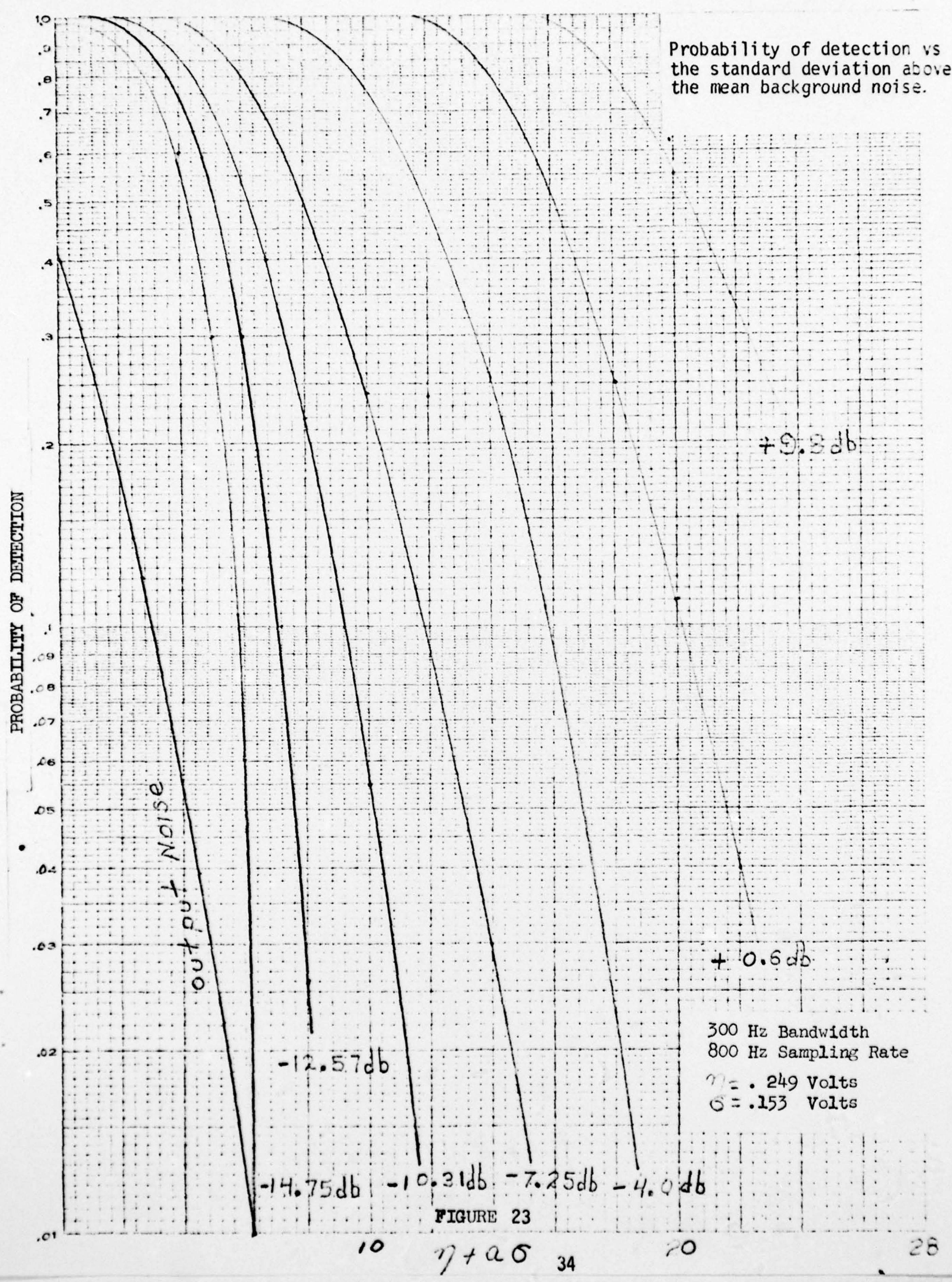

Probability of detection vs the standard deviation above the mean background noise.
PROBABILITY OF DETECTION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
10
20
25
$\eta + a\sigma$
output Noise
-14.75db
-12.57db
-10.31db
-7.25db
-4.0db
+0.6db
+9.8db
300 Hz Bandwidth
800 Hz Sampling Rate
η = .249 Volts
σ = .153 Volts

FIGURE 23

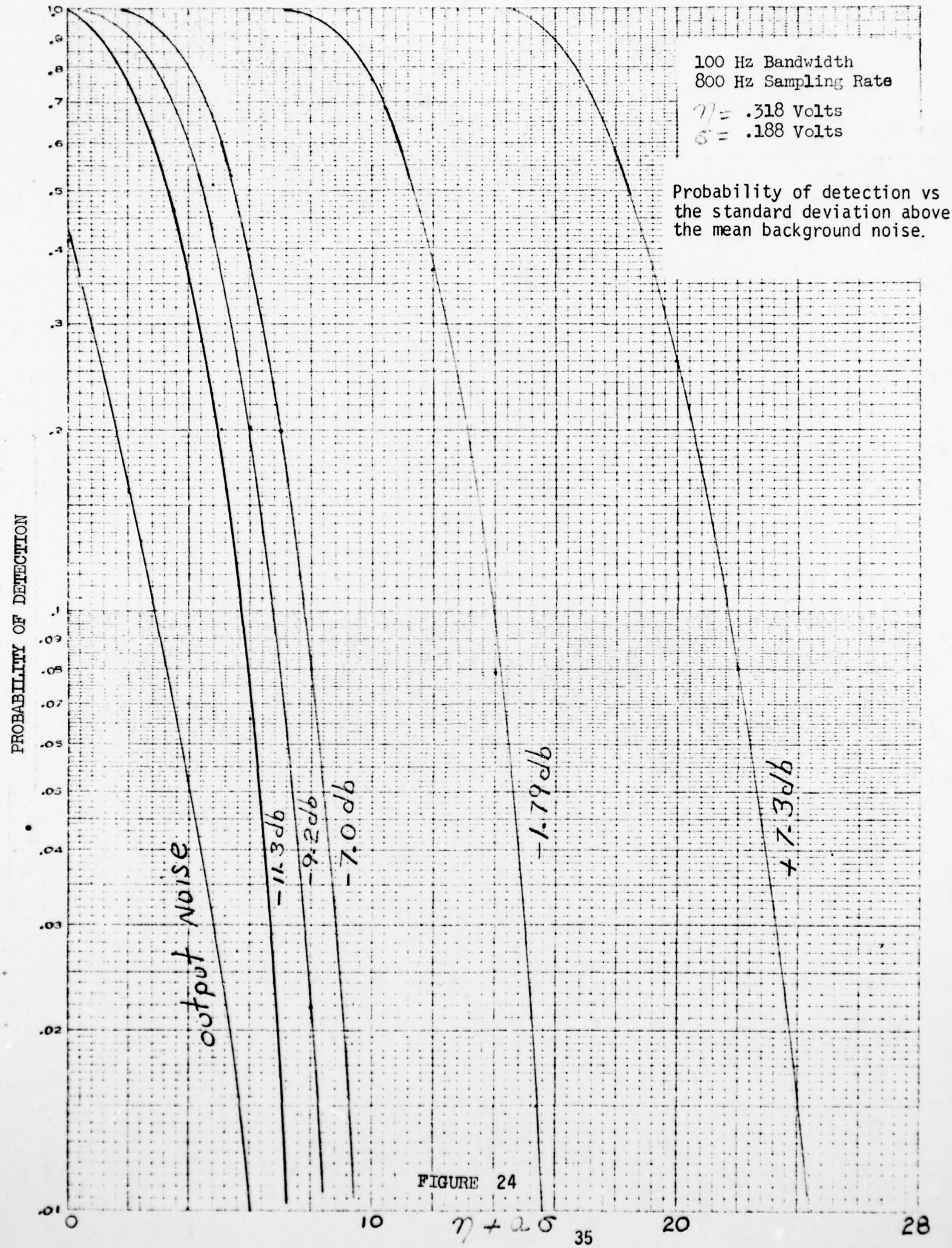

100 Hz Bandwidth
800 Hz Sampling Rate
η = .318 Volts
σ = .188 Volts
Probability of detection vs the standard deviation above the mean background noise.
PROBABILITY OF DETECTION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
10
20
28
η + a σ
output Noise
-11.3db
-9.2db
-7.0db
-1.79db
+7.3db

FIGURE 24

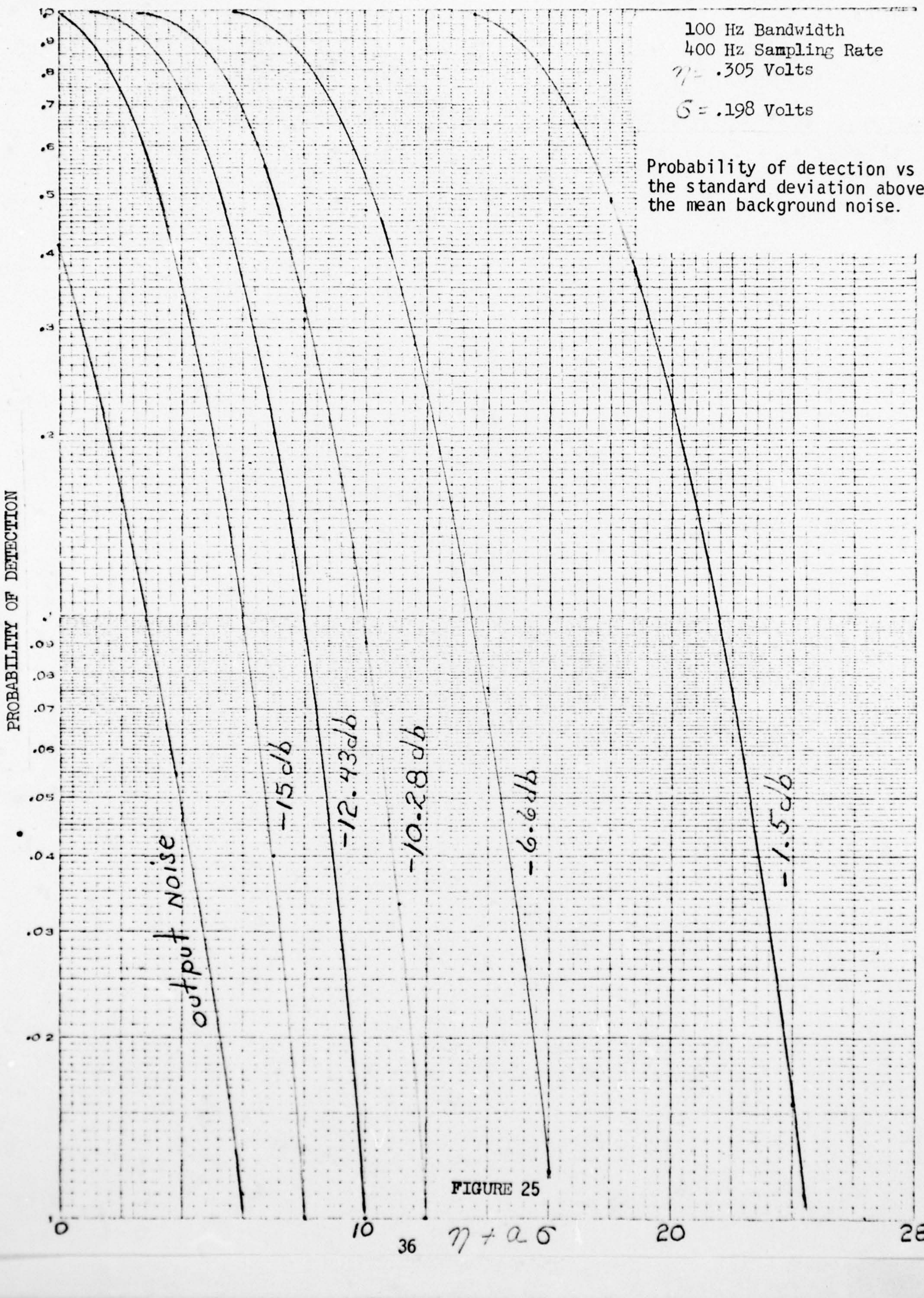

100 Hz Bandwidth
400 Hz Sampling Rate
η = .305 Volts
σ = .198 Volts
Probability of detection vs the standard deviation above the mean background noise.
PROBABILITY OF DETECTION
output noise
-15db
-12.43db
-10.28db
-6.6db
-1.5db
0
10
20
28
η + aσ

FIGURE 25

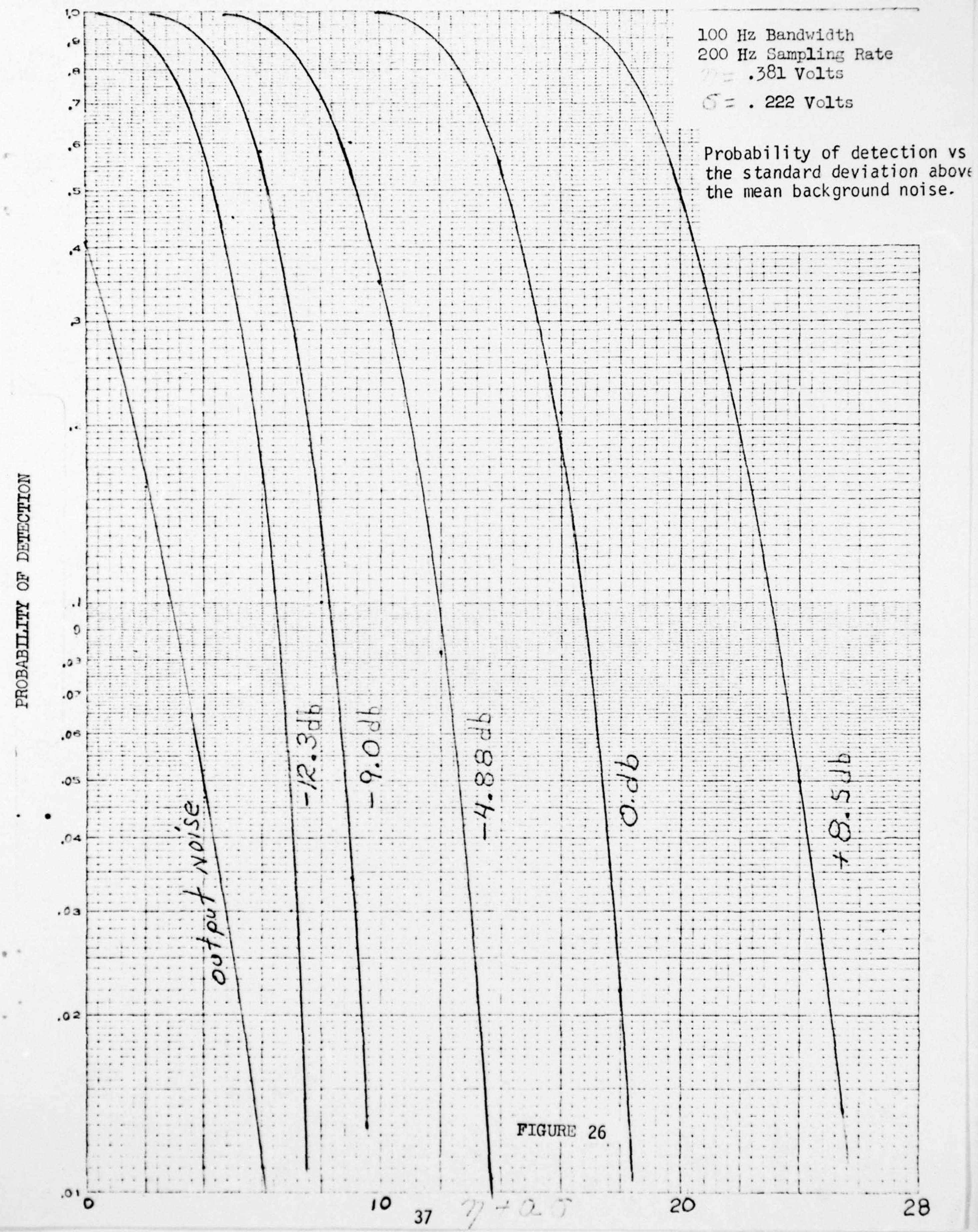
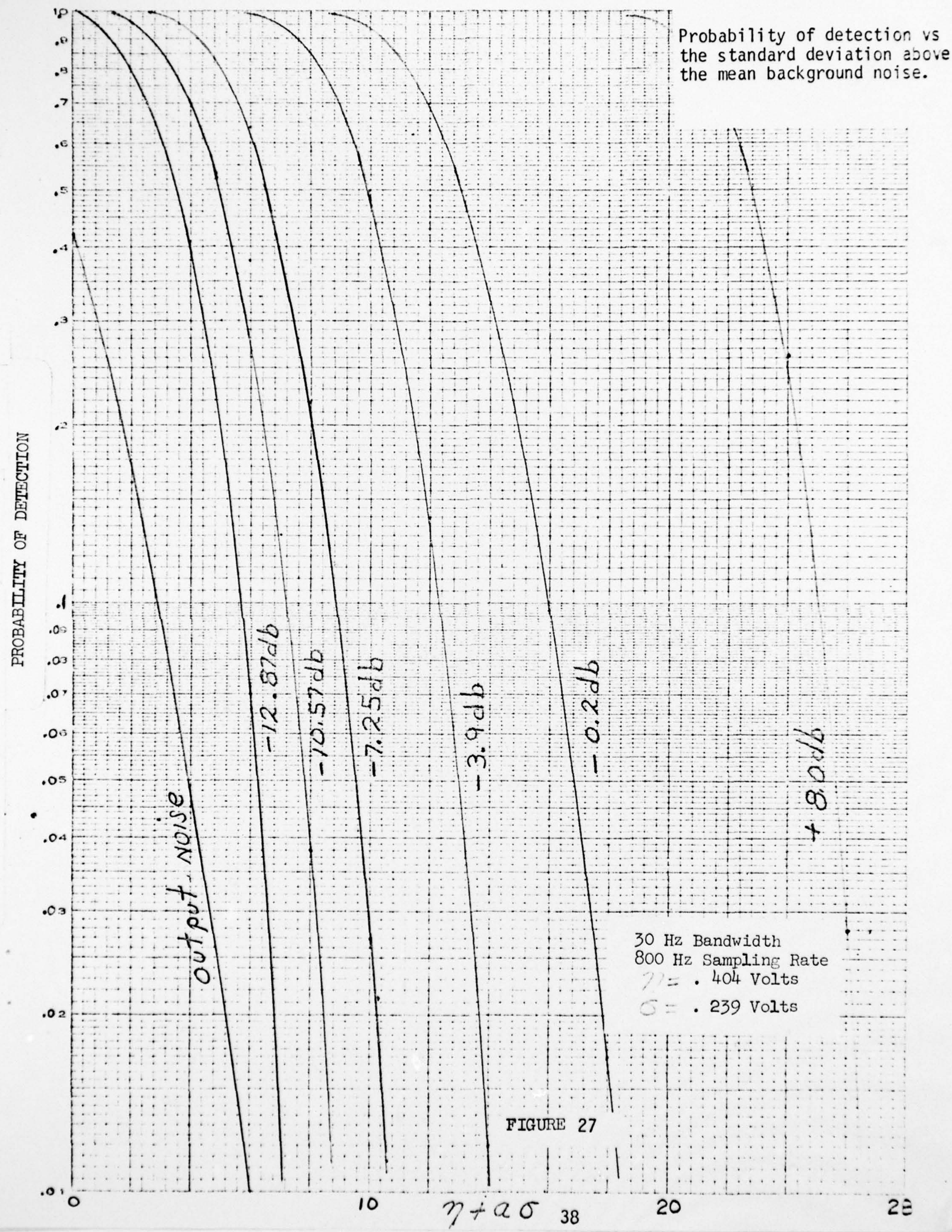
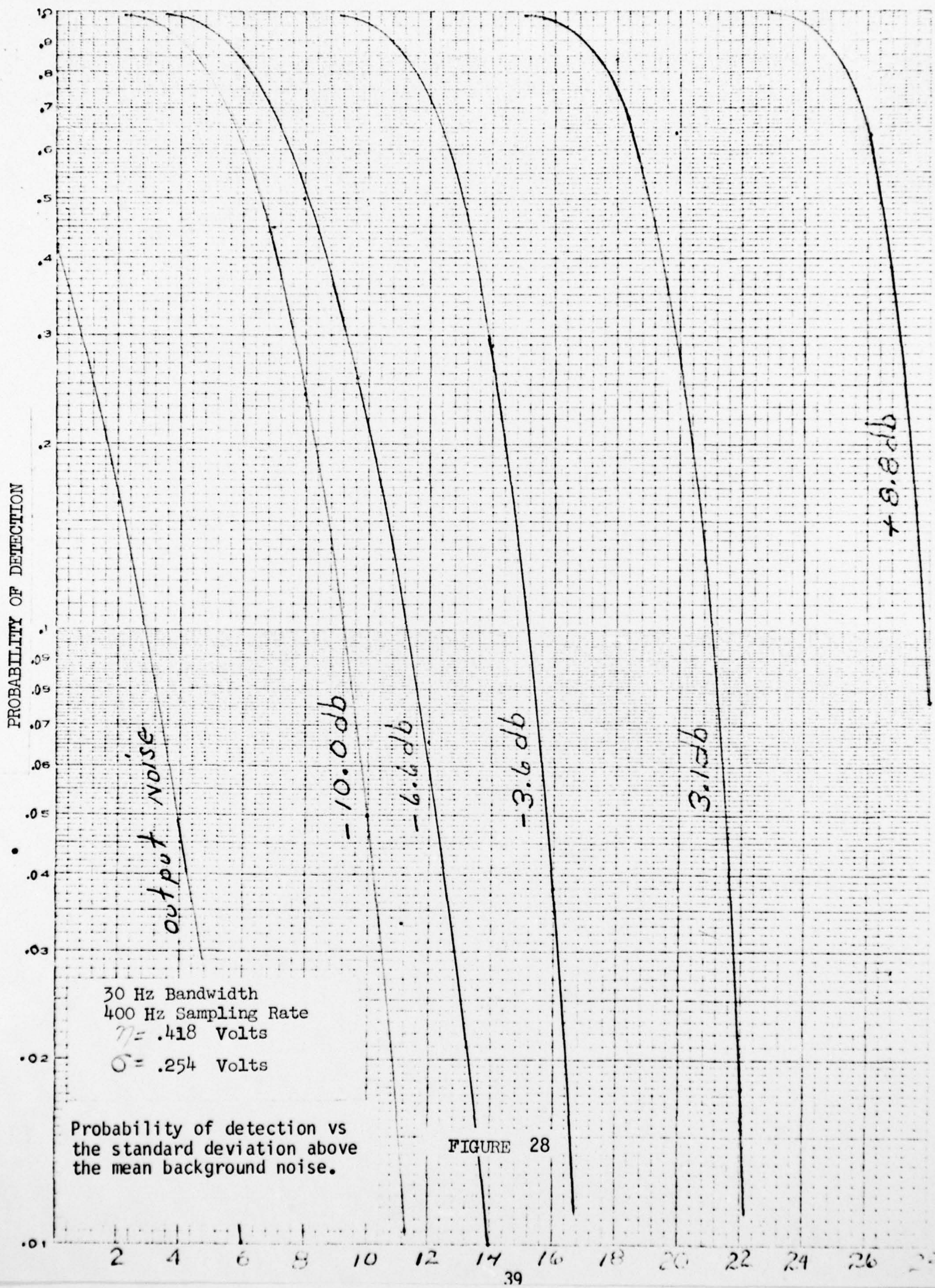

100 Hz Bandwidth
200 Hz Sampling Rate
η = .381 Volts
σ = . 222 Volts
Probability of detection vs the standard deviation above the mean background noise.
PROBABILITY OF DETECTION
output noise
-12.3 db
-9.0 db
-4.88 db
0. db
+8.5 db
0
10
20
28
$\eta + a\sigma$

FIGURE 26



Probability of detection vs the standard deviation above the mean background noise.
PROBABILITY OF DETECTION
output noise
-12.87db
-10.57db
-7.25db
-3.9db
-0.2db
+8.0db
30 Hz Bandwidth
800 Hz Sampling Rate
η = .404 Volts
σ = .239 Volts
0
10
20
$\eta + a\sigma$

FIGURE 27



Probability of detection vs the standard deviation above the mean background noise.

FIGURE 28

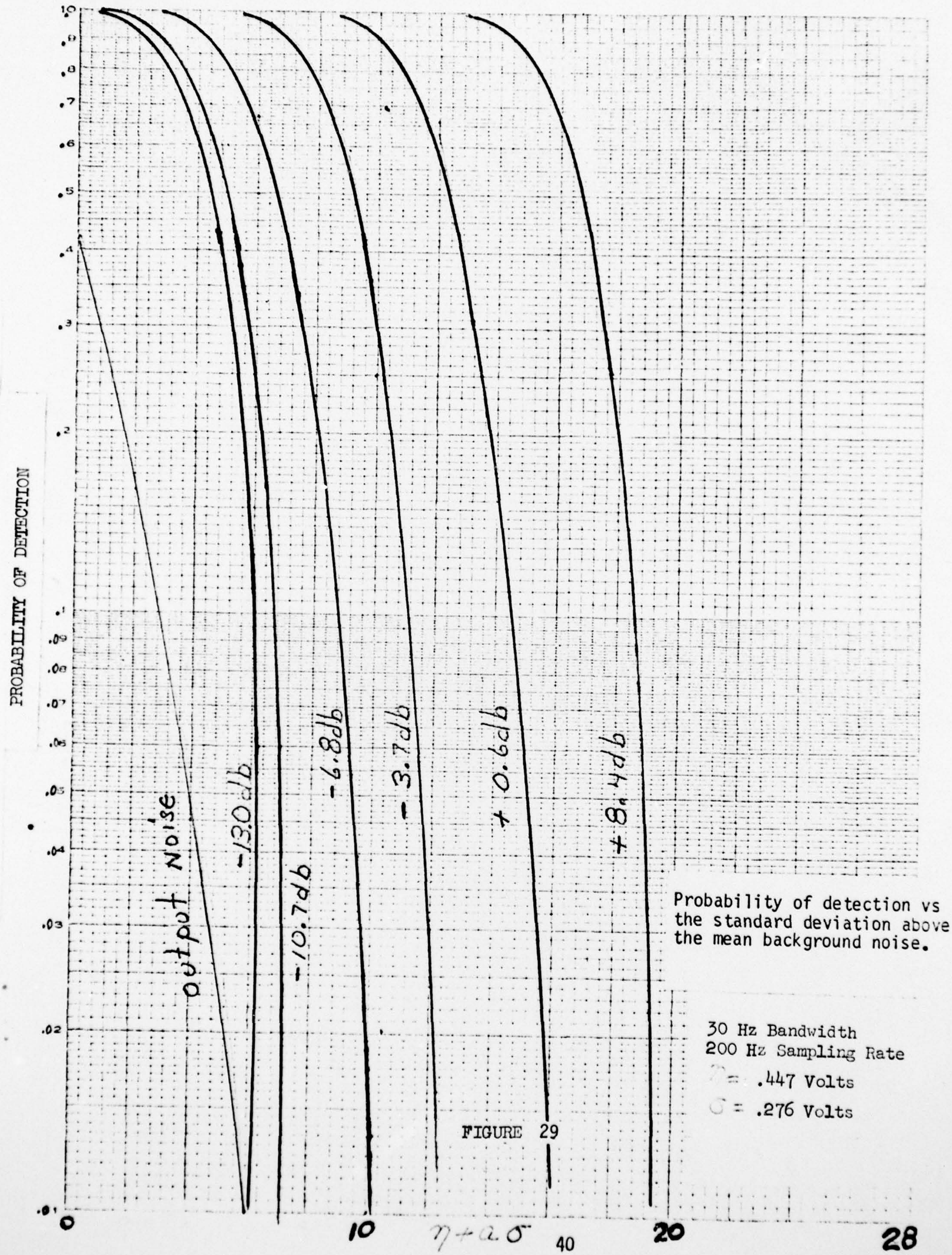
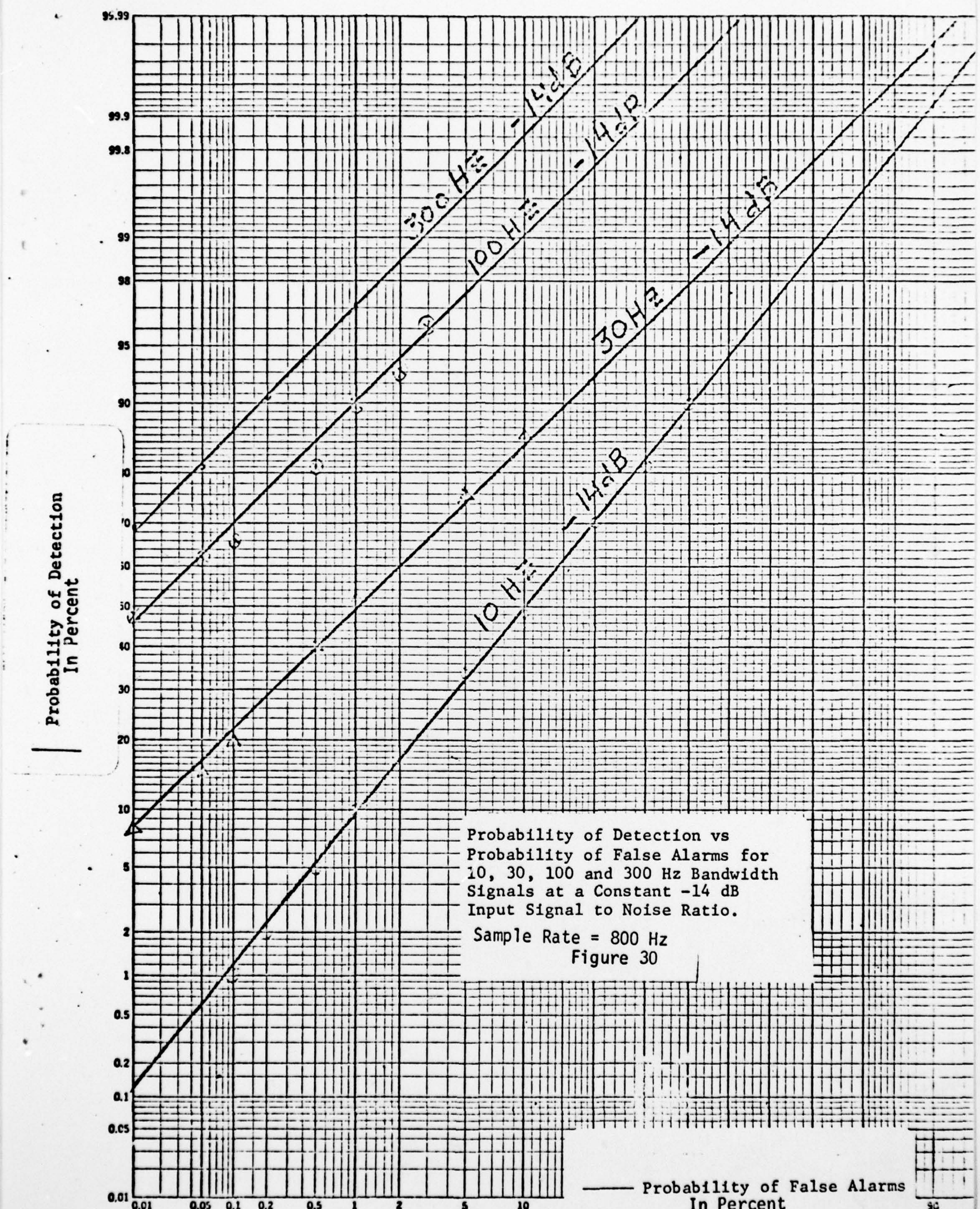


FIGURE 29

Probability of detection vs the standard deviation above the mean background noise.

30 Hz Bandwidth
200 Hz Sampling Rate
η = .447 Volts
σ = .276 Volts



Probability of Detection vs Probability of False Alarms for 10, 30, 100 and 300 Hz Bandwidth Signals at a Constant -14 dB Input Signal to Noise Ratio.

Sample Rate = 800 Hz

Figure 30

BANDWIDTH	SAMPLE RATE	MEAN η VOLTS	STANDARD DEVIATION σ VOLTS
300	800	.249	.153
100	800	.318	.188
	400	.305	.198
	200	.381	.222
30	800	.404	.239
	400	.418	.254
	200	.447	.276

OUTPUT NOISE

TABLE 1